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FLIGHT TEST OF A COMPOSITE MULTI-TUBULAR SPAR MAIN ROTOR BLADE --ETC(U)

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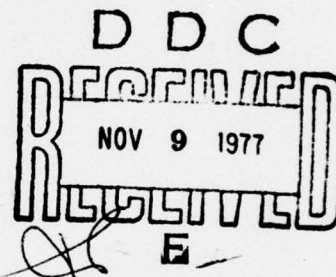
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**FLIGHT TEST OF A COMPOSITE MULTI-TUBULAR SPAR MAIN
ROTOR BLADE ON THE AH-1G HELICOPTER
Volume II - Cost Estimates and Process Specifications**

Hughes Helicopters
Division of Summa Corporation
Culver City, California 90230



August 1977

Final Report for Period June 1974 - January 1977

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Prepared for

**EUSTIS DIRECTORATE
U. S. ARMY AIR MOBILITY RESEARCH AND DEVELOPMENT LABORATORY
Fort Eustis, Va. 23604**

EUSTIS DIRECTORATE POSITION STATEMENT

The work reported herein was performed under Contract DAAJ02-74-C-0055 with Hughes Helicopter Company, Culver City, California, and Fiber Science, Inc., Gardena, California, as primary contractor and subcontractor respectively.

The data contained in this report are the results of flight and laboratory testing. The reported work was performed to determine the applicability of the filament winding co-cure fabrication process, in conjunction with the Multi-tubular Spar concept, in fabricating rotor blades with improved fatigue life, ballistic damage tolerance, low radar cross-section signature, and low production cost.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The objectives of this program were to design a composite main rotor blade in the multi-tubular spar configuration to be directly interchangeable (in pairs) with the production metal (540) blades on the AH-1G helicopter, have increased fatigue life, invulnerability to the 23mm ballistic threat, low radar cross section, and low fabrication cost. Manufacturing technology was developed and described in a Process Specification. Laboratory, ground, and flight tests demonstrated that the wet filament wound, co-cured blade met, and in some cases surpassed, all objectives and could be adapted for Army service.		

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PREFACE

This report was prepared by Hughes Helicopters, Division of Summa Corporation, Culver City, California 90230, for the U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia 23604, under Contract DAAJ02-74-C-0055.

Hughes Helicopters (HH) was the prime contractor and Fiber Science, Inc. (FSI) was the subcontractor. HH and FSI cooperated on the design, FSI fabricated the blades, and HH tested them. Mr. R. E. Head was HH program manager and Mr. L. Ashton was program manager at FSI. The Eustis Directorate technical monitor for the programs were Mr. I. E. Figge and Mr. N. J. Calapodas.

The final report on the development program for the composite multi-tubular spar (MTS) main rotor blade for the AH-1G helicopter is presented in three volumes: Volume I, Materials, Design, and Test; Volume II, Cost Estimates and Process Specifications; and Volume III, (S) Ballistic Damage Tolerance and Radar Cross Section.

This volume describes how the material and labor costs were documented and projected forward to establish production costs. It also documents the production process for manufacturing the R&D blade.

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INTRODUCTION

This volume describes the production cost aspects of the wet-filament-wound (WFW) composite main rotor blade, and presents a process specification for its manufacture. Ten full-size blades were fabricated in this program -- two for toolproofing and eight for test.

While building the eight test blades, records were kept of the labor hours required to make each blade, and the cost of the materials that went into it. From these data projections are made for total manufacturing costs for MTS blades produced at a rate of 1000 per year. HH industrial engineering group made these estimates based on a conservative application of industry-recognized methods. Two assumptions that enhance this conservatism are that the first production blade will require as many man-hours to build as the last R&D blade, and that by the time the 300th blade has been fabricated all production improvement will have been realized and no further reduction in man-hours will occur.

The Process Specification for fabricating the MTS blade is written in the form prescribed by Appendix XIV, Process Specification, MIL-STD-490. The wet-filament winding, co-cure process was modified while building the early test blades to improve the ease and repeatability of manufacturing. This specification was developed jointly by HH and FSI and represents the culmination of this improvement. In particular, it describes the method by which the two flight test blades and one spare blade (S/N-006, -007, and -008) were built.

SECTION I - PRODUCTION COST ASSESSMENT

The cost assessment includes a description of the manufacturing process, manufacturing labor costs, materials costs, and nonrecurring costs. A cost estimate for producing 10,000 MTS blades is also presented. Additional cost data is given in Appendixes A, B, C, and D.

MANUFACTURING PROCESS

The manufacturing process used for fabricating the eight R&D MTS blades is shown schematically in Figure 1.

LABOR COSTS

The direct labor hours incurred at both HH and FSI in building the MTS blades were determined from accounting records. The blade costs are reported with three types of labor man-hours represented:

- a. Direct "hands-on" time in which workers are actually fabricating blade components, putting components together in final assembly, monitoring the blade curing cycle, or engaged in finishing operations.
- b. Time during which the *personnel are required to be present*, but are not contributing directly to the blade building process.
- c. Supervision, quality control, liaison, and general observation of this new way of fabricating a rotor blade.

The overall time charged to the program was taken directly from time cards. The "hands-on" time record was kept by a HH monitor who closely observed who was doing what and for how long. The supervision, quality control, liaison and observation categories were based on the accounting records. These blades were built in a research and development environment. In a production shop, better utilization of manpower would be possible.

Table 1 shows touch-times clocked during fabrication of the S/N-008 blade; the final blade built under the development. Touch-time is described as the actual "hands-on" fabrication time, including in-process tool preparation

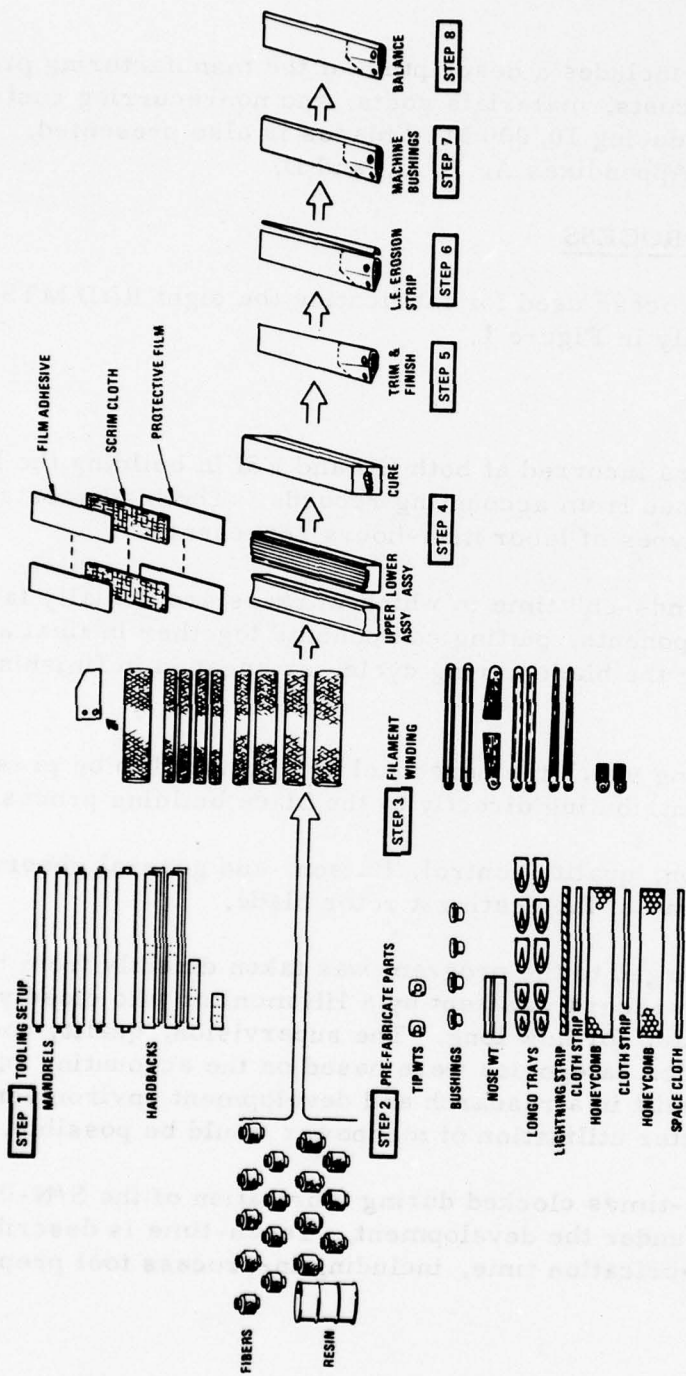


Figure 1. MTS blade fabrication process schematic - R&D fabrication.

TABLE 1. DISTRIBUTION OF LABOR

Process Steps	R&D Touch-Time	
	(man-hours)	(percent)
1. Tooling Setup	60	18
2. Parts Prefabrication	74	22
3. Filament Winding	45	13
4. Assembly and Curing	78	24
5. Trim and Finish	52	16
6. Erosion Strip Installation	4	1
7. Final Machining	12	4
8. Balancing	<u>8</u>	<u>2</u>
	333	100

and cleanup. The touch-time details are given in Appendix A. More information on the WFW process may be found in Reference 1.

The direct labor hours are plotted in Figure 2, and include both touch-time and support time. Support time is that associated with quality control, factory and engineering supervision, interprocess transportation, tool repair, liaison, and other processing requirements. A total of 1295 labor hours were required for the S/N-001 blade; this dropped to 772 hours for S/N-008. All eight blades were built on R&D tooling. Blades S/N-001 and S/N-002 were built in a 2-month period, followed by a 6-month shutdown for testing; the final six blades were fabricated during a 10-week period. Winding and assembly for each of the final six blades was accomplished within one week, with the S/N-008 blade requiring 333 hours of touch-time labor.

¹ Lund, H. T., and Needham, J. F., DESIGN, FABRICATION, AND TESTING AN ADVANCED COMPOSITE AH-1G TAIL BOOM, Hughes Helicopters, AHS Paper, American Helicopter Society, Washington, D. C., 1976.

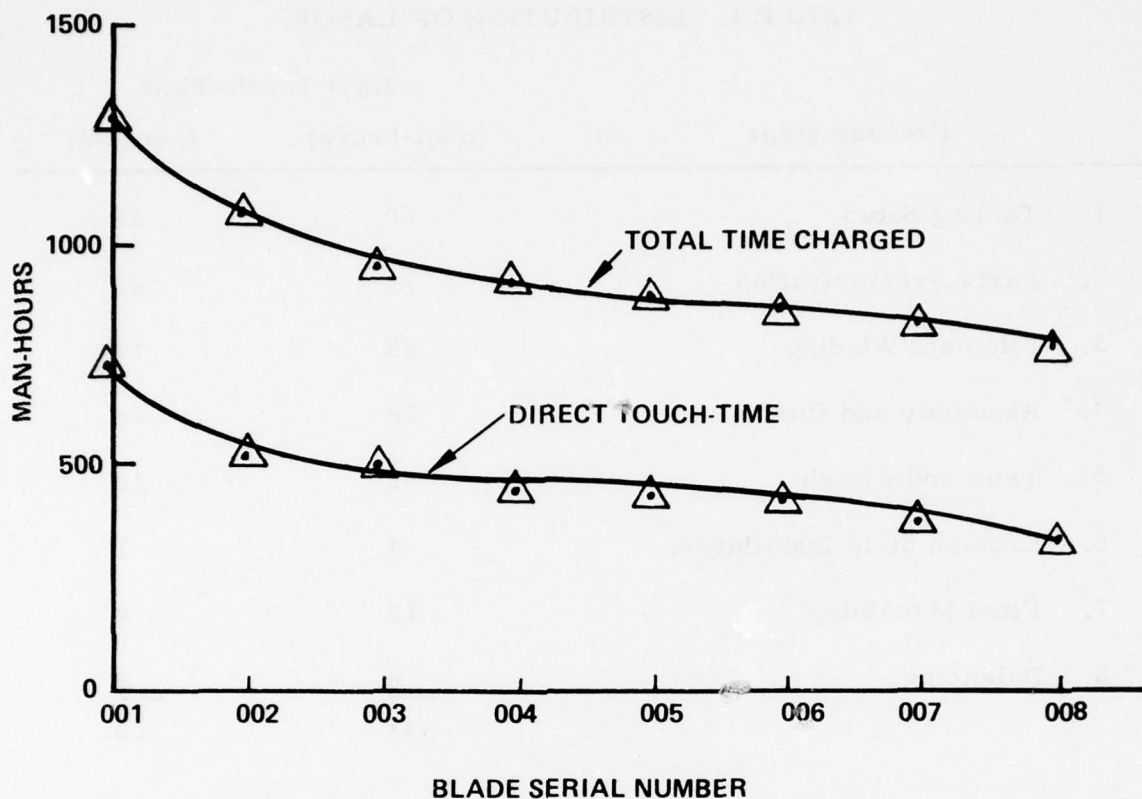


Figure 2. MTS R&D blade man-hour record.

PRODUCTION LABOR COST PROJECTION

The man-hour estimate for fabricating MTS blades on a production basis is based on the R&D manufacturing process record and recommendations of HH industrial engineering group. The touch-time distribution between the process steps for the S/N-008 blade is listed in Table 2. A production improvement curve for each step is applied to arrive at the anticipated touch-times in production. Conservative improvement factors are assumed in all cases to assure the most credible production cost estimate. A production improvement curve of 87 percent is applied to each step that is a labor-intensive process step (1, 4, 5, 6), including the WFW step (3). A curve of 93 percent is applied to each machine-intensive step (7, 8). Step 2 is eliminated in production by purchasing these components rather than fabricating them in-house. Overall, the touch-time functions follow an 88-percent improvement curve.

TABLE 2. MTS BLADE LABOR SUMMARY

Process Steps	Unit Touch-Time for Blade			Straight Line Unit Improve- ment Curve (percent)
	R&D S/N-008 (Actual man-hours)	Production S/N-001 (Estimated man-hours)	S/N-300 (Estimated man-hours)	
1. Mold and Tooling Preparation	60	60	19	87
2. Parts Prefabrication	74	(Purchased)	-	-
3. Wet-Filament Winding	45	45	16	87
4. Assembly and Cure	78	78	24	87
5. Trim and Finish	52	52	16	87
6. Leading Edge Erosion Strip	4	4	2	87
7. Root End Machining	12	12	7	93
8. Balance and Final Inspection	<u>8</u>	<u>8</u>	<u>5</u>	<u>93</u>
Touch-Time	333	259	89	88
Support	439	439	26	71
TOTAL	772	698	115	

The support function is assumed to follow a 71-percent improvement curve, which is conservative with respect to factors that have been experienced by and recommended by HH industrial engineering and companies such as McDonnell Douglas and Rand Corporation. Support personnel perform the following functions:

- a. Shop Supervision
- b. Project Coordination
- c. Sustaining Engineering
- d. Quality Control
- e. Tool and Test Equipment Maintenance and Repair

Table 2 shows that the touch-time should go from 259 man-hours for the S/N-001 production blade to 89 man-hours for the S/N-300 production blade when all learning experience has been applied. Support time is expected to be reduced from 439 man-hours to 26 man-hours over the same span. The total time will fall from 698 man-hours to 115 man-hours per blade.

Based on the advice of HH industrial engineering group, it is assumed that the first production blade will take just as many man-hours (259 touch-time, 439 support, 698 total) as the last R&D blade, even though superior tools and fixtures will be employed. It is further assumed that full production improvement will be achieved by the time the 300th blade is built (89 touch-time man-hours, 26 support man-hours, 115 total man-hours). After the 300th blade, no further improvement is assumed. Figure 3 shows this estimate.

Based on the 115 man-hour estimate for building the 300th blade, and using a burdened labor cost of \$14.44 for touch-time labor and \$20.00 for support labor per man-hour (FY 1976 wage rate), the manufacturing labor cost for each blade beginning with S/N-300 will be \$1805 per blade.

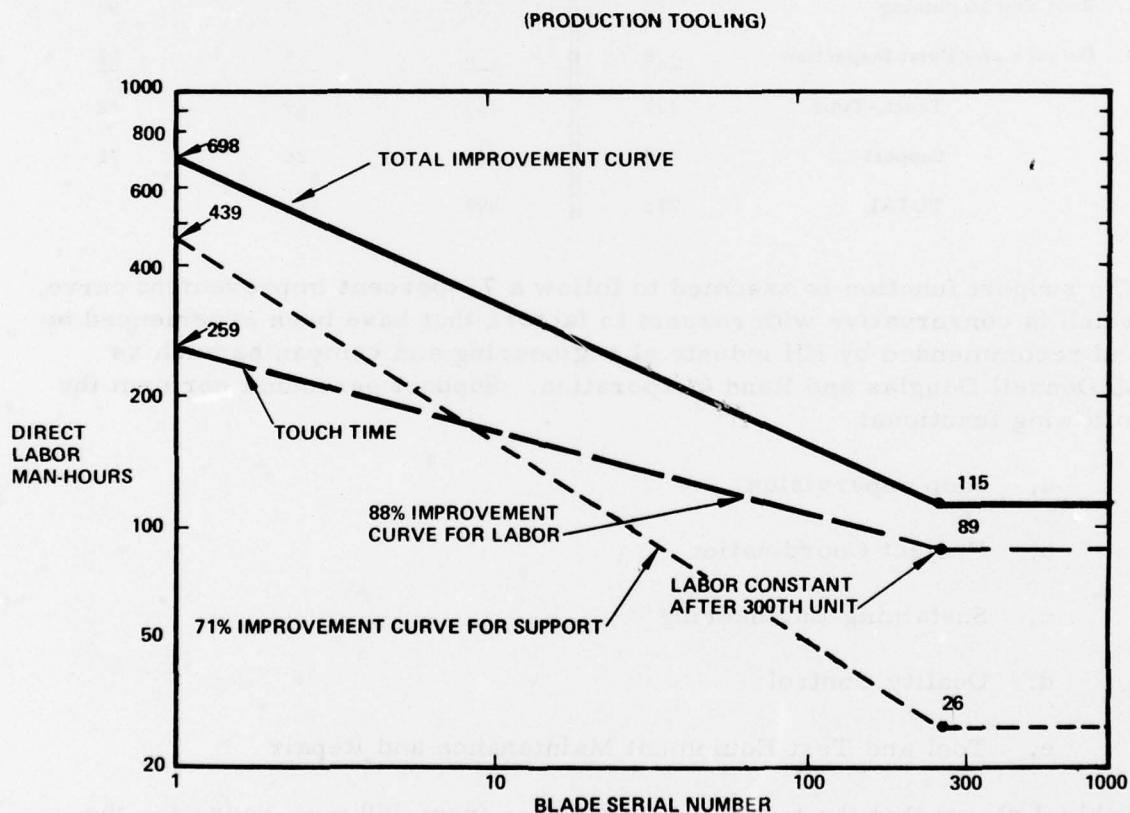


Figure 3. MTS production blade man-hour estimate.

MATERIALS COST

The 15 major materials used in the MTS blade are listed in Table 3. Material costs for the initial R&D blades, listed under the heading "S/N-008," total \$3646 per blade. (Material costs were taken from invoices.) Based on quotations for a quantity buy for 1000 blades, the material cost for the first 1000 blades is expected to be \$2137 per blade. Both of these figures include a 10-percent scrap and rework allowance, plus an 8.1-percent material burden. The production blade material list includes a \$150 quotation per blade for the purchase of prefabricated parts. (These are the parts whose production labor cost was shown to go to zero in Table 2.)

To make 1000 MTS blades a year, approximately 220,000 pounds of filaments-plus-resin must be wet filament wound (this includes 10 percent scrap plus the unusable end material). The two machines used to wind MTS blades consistently delivered WFW components at a rate more than sufficient to build 1000 MTS blades per year, assuming production on a two-shift basis.

A benefit of the WFW process is that, if a component is observed to be winding incorrectly, the machine can be stopped, the bad material unwound, and the part properly rewound. In metal technology, once a part is improperly formed or machined, the whole unit is lost. In WFW, only the bad windings need be thrown away.

NONRECURRING MANUFACTURING COSTS

The nonrecurring costs associated with manufacturing the MTS blade are those required to set up the manufacturing facility for building the blade. A tentative layout for production, Figure 4, assumes a two-shift operation, 6 days per week to build MTS blades at the rate of 1000 blades per year. HH and FSI industrial engineering groups estimate that the production facility, housed in approximately 13,000 square feet of manufacturing space (the building itself is not costed here), requires the equipment in Table 4.

The manufacturing facility includes rooms for the following processes: assembly and molding, trimming and finishing, root machining, and painting. The trim room is environmentally isolated from the others, and the winding room is well ventilated to carry off resin fumes. Ancillary facilities are office area, materials storage room, quality control room, balancing room, and shipping room.

TABLE 3. MATERIAL COSTS MTS BLADE

Material	Amount Used	Actual R&D		Quotations for Production	
		Unit Cost	S/N-008	Unit Cost	S/N-1000
S-Glass	36 lb	\$ 5.10/lb	\$ 184	\$ 1.65/lb (S-2 glass)	\$ 59
E-Glass	9 lb	\$ 0.35/lb	\$ 3	\$ 0.60/lb	\$ 6
Thornel-300	4 lb	\$ 50.00/lb	\$ 200	\$ 20.00/lb	\$ 80
Kevlar-49	60 lb	\$ 8.50/lb	\$ 510	\$ 6.50/lb	\$ 390
Resin	120 lb	\$ 1.87/lb	\$ 224	\$ 1.25/lb	\$ 150
Space Cloth	9 ft ²	\$ 65.00/ft ²	\$ 585	\$ 30.00/ft ²	\$ 270
Tip Weights	3	-	\$ 460	-	\$ 200
Root-End Bushing and Sleeves	2 & 2	-	\$ 335	-	\$ 100
Honeycomb	3 sheets	\$ 61.05/sheet	\$ 183	\$ 50.00/sheet	\$ 150
Erosion Strip	19 ft	\$ 9.00/ft	\$ 171	\$ 7.00/ft	\$ 133
Tedlar Film	1/3 roll	\$150.00/roll	\$ 50	\$100.00/roll	\$ 33
Film Adhesive	200 ft ²	\$ 0.50/ft ²	\$ 100	\$ 0.20/ft ²	\$ 40
Milled E-glass Fiber	12 lb	\$ 0.77/lb	\$ 9	\$ 0.58/lb	\$ 7
Microballoons	3 lb	\$ 7.40/lb	\$ 22	\$ 6.40/lb	\$ 19
Prefabricated Parts (Trays, Bags, Filler Blocks, Tabs, Dams)	-	Fabricated in Process		Bid Purchase	\$ 150
Miscellaneous	-	-	\$ 30	-	\$ 10
10 Percent Scrap and Rework Allowance	-	-	\$ 307	-	\$ 180
8.1 Percent Purchasing and Receiving Inspection Burden	-	-	\$ 273	-	\$ 160
TOTAL			\$3646		\$2137

TABLE 4. MTS BLADE PRODUCTION TOOLING AND EQUIPMENT
COST ESTIMATE - NONRECURRING

	Number Required	Price Each (\$)	Cost Estimate (\$)
1. Heated Mold	4	70,000	280,000
Process Cycle - 8 hours to load, 6 hours low-temperature cure; 6 hours high-temperature cure; 4 hours to cool; 1 hour to unload; 3 hours miscellaneous			
Assume a 24-hour cycle for cure in each mold, with 1 mold extra for production load cycling/ schedule			
2. Winding Fixture - Longo	1	15,000	Capital Equipment
77.3 lb wet windings per blade x 3 blades/16 hours = 14.4 lb/hr			
Single machine capacity - 25/lb hour			
3. Winding Machine - Tubular	1	50,000	Capital Equipment
100 lb wet windings x 3 blades/16 hours = 18.7 lb/hr			
Single machine capacity 25 lb/hr			
4. Mandrels and Hardbacks	3 sets	5,000	15,000
(7 mandrels + 10 hardbacks) per set			
5. Fixtures and Jigs	1 set	30,000	30,000
Holding fixtures for 3 blades per day in process			
6. Milling Machine and Drill	1 set	75,000	Capital Equipment
For attachment bushing boring and facing			
7. Other	1 set	100,000	100,000
Miscellaneous special equipment, scales, contour check fixture, weight and balance equipment, etc.			
Subtotal			425,000
Purchasing Burden @ 8.1 Percent			34,425
TOTAL			459,425

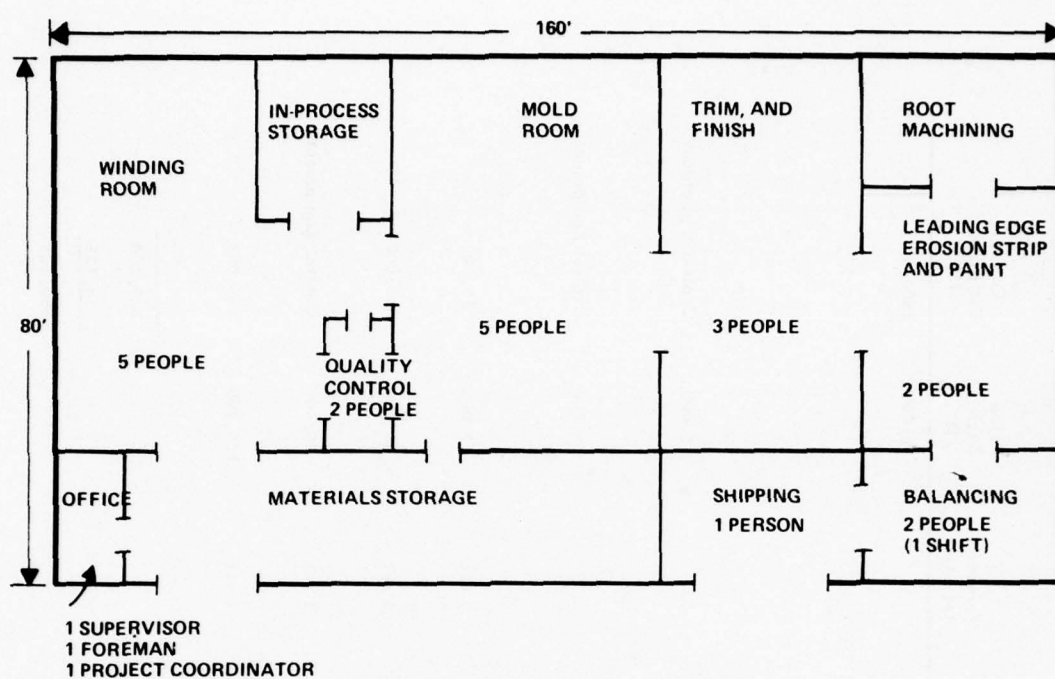


Figure 4. Proposed production facility for MTS blade.

It is estimated that in addition to acquiring the necessary manufacturing equipment, 50 man-months of labor are needed over a 9-month period to modify and equip an existing manufacturing facility to make it ready for building composite blades. This includes effort by engineering, manufacturing planning and tooling, and product assurance. Figure 5 shows the proposed MTS blade production buildup schedule.

MTS PRODUCTION BLADE COST FOR 10,000 BLADES

Because rotor blades are usually built in large numbers for any production helicopter, a statement of cost is meaningful only in production runs of 1,000 blades or more. The analysis given in this report is based on WFW technology that has already been demonstrated in the MTS blade program, and on cost projections by methods generally recognized in the industry. The nonrecurring cost is amortized over the first 2000 blades, with the startup learning process considered to take place while building the first 300 blades.

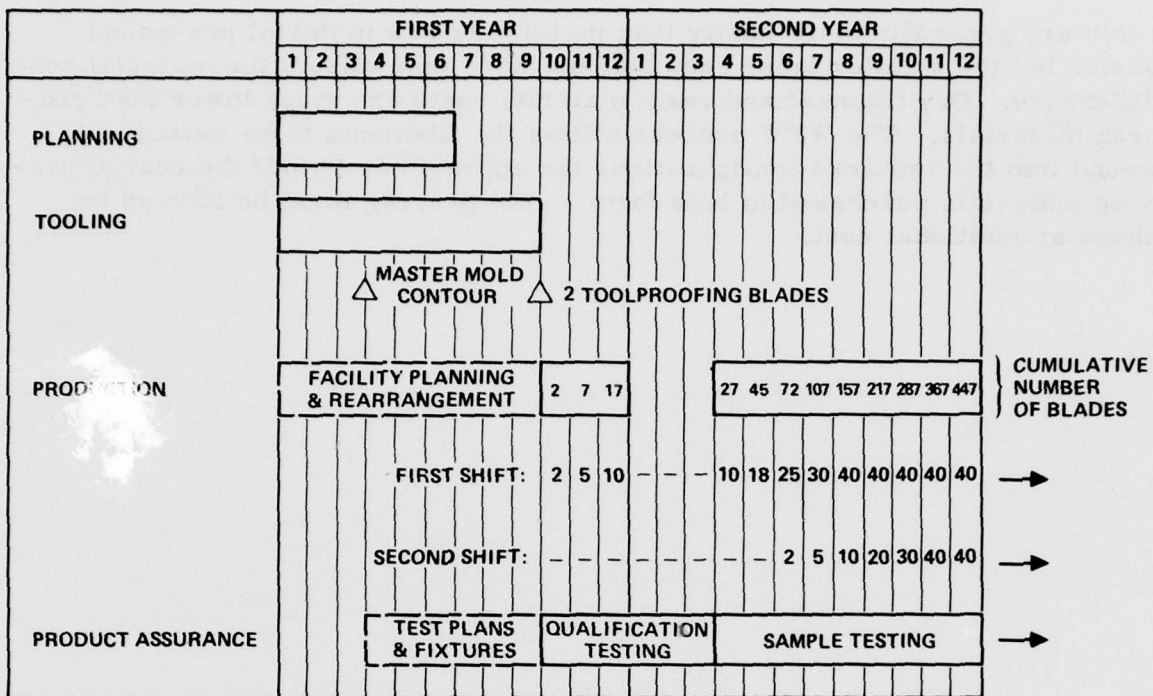


Figure 5. Proposed MTS blade production buildup schedule.

The production cost estimate for 10,000 MTS blades is based on the design as it presently exists. It is assumed that a composite manufacturing facility would be set up at HH, and that all major manufacturing functions would be performed there. Industry experience with production improvement (learning curve factors) has been applied to the labor data gathered for the eight MTS blades built in the research and development program, and volume-buy material cost estimates were used.

Adding a 28-percent factor for G&A, IR&D, and fees to the labor and material cost described above, the first 2000 production blades would have a unit selling price of \$5561 and the remainder of the production run would have a per-blade selling price of \$5050. Thus, in FY 1976 dollars, the 10,000-blade production run would have a price of \$51,522,000.

In performing the production cost analysis, a comparison was made of the WFW process and the pre-impregnated (prepreg) material layup process and metal technology. The analysis shows that the WFW, co-cure process is more cost effective than is the more conventional prepreg layup process, and shows special advantages over metal technology. This is achieved by automation, and by drawing dry filaments from factory-wound spools and resin from the shipping drum -- both at their lowest cost. Filaments and

SECTION II - PROCESS SPECIFICATION

This section is the Process Specification used for fabricating the MTS blade. The text paragraphing generally conforms to the form prescribed by Appendix XIV, Process Specification, MIL-STD-490. Upon approval as a production specification, this section is amenable to complete formatting in accordance with MIL-STD-490.

The WFW, co-cure process was continuously modified to improve the ease and repeatability of manufacturing during the period when the MTS blades were being built. The process specification presented here was developed by HH and FSI personnel and represents the culmination of this improvement. It describes the method by which the two flight test and one spare MTS blades, S/N-006, S/N-007, and S/N-008, were built.

This specification is directly applicable only to the research and development blades fabricated under this program but in general represents the method by which production blades would be manufactured.

Basic drawings for the blade may be found in Volume I. Appendix E contains photographs of tools and fixtures.

PROCESS SPECIFICATION

MULTI-TUBULAR SPAR COMPOSITE MAIN ROTOR BLADE

FOR AH-1G HELICOPTER

1. SCOPE. The specification defines the materials and processes required for fabricating the Multi-Tubular Spar (MTS) composite main rotor blade for the AH-1G helicopter.

2. APPLICABLE DOCUMENTS.

2.1 Drawing No. 503-001 (Figures 39 through 46, Volume I).

2.2 Process Specification, HP 9-26D: Etch and Priming of Austenitic Corrosion-Resistant Steel for Adhesive Bonding.

2.3 Process Specification, HP 4-35F: Anodic Treatment of Aluminum Alloys for Metal-to-Metal Bonding.

2.4 Process Specification, HP 9-27A: Etching/Priming of Copper Alloys for Adhesive Bonding.

2.5 Process Specification, HP 15-38C: Installation of Bearings/Bushings.

2.6 Process Specification, HP 9-1-J: Abrasive Cleaning Methods for Metallic and Nonmetallic Parts.

3. REQUIREMENTS. The MTS blade is designed to be a direct replacement (in pairs) for the production metal blade currently installed on AH-1G helicopters. Its planform, twist, and airfoil section (outboard of Blade Station (BS) 85) are the same as the metal blade. Its weight distribution and dynamic properties are similar. The blade is made by the WFW, co-cure process and is made entirely of composite materials with the exception that retention bolt bushings at the root end and the tip weights are metal.

3.1 Equipment. The special equipment needed to fabricate the MTS blade shall consist of:

	<u>Equipment</u>	<u>Photograph (Appendix E)</u>
3.1.1	Winding mandrel, outer skin	E-1
3.1.2	Winding mandrel, spar tube	E-2
3.1.3	Winding fixture, longo	E-3
3.1.4	Longo hardback	E-4
3.1.5	Bonding fixture, bladder	E-5
3.1.6	Blade mold	E-6
3.1.7	Impregnator, resin	E-7
3.1.8	Locating gage, spar tube	E-8

3.2 Materials. The materials required to fabricate the MTS blade shall be as listed below:

- 3.2.1 Kevlar-49, 1420 denier roving*
- 3.2.2 Thornel-300 graphite roving*
- 3.2.3 Style 104 E-glass fabric
- 3.2.4 Style 112 E-glass fabric
- 3.2.5 Style 1581 E-glass fabric
- 3.2.6 S-1014, 9-end S-glass roving*
- 3.2.7 KGF-K37-274 E-glass roving*

*See Table 5 for filament density characteristics.

TABLE 5. COMPOSITE MATERIAL DENSITY

Type of Fiber	Fiber		Resin	Composite	
	Density lb/in. ³	Area in. ² x 10 ⁻⁶	Density lb/in. ³	Fiber/Resin Volume Percent	Density lb/in. ³
Kevlar 49	0.0524	168.66	0.0412	50	0.0468
S-Glass	0.0900	191.25	0.0412	50	0.0656
				55	0.0680
E-Glass	0.0920	83.35	0.0412	50	0.0666
Thornel 300	0.0636	168.01	0.0412	50	0.0524

The number of rovings and bands specified for WFW operations in Paragraph 3.3 are based upon the fiber density values shown above. Spools of filaments used to form the roving bands shall be individually selected to achieve an overall accuracy of density to within ± 5 percent.

3.2.8 Milled E-glass fibers mixed with Paragraph 3.2.12 epoxy resin system. Fiber ratio = 0.50 by weight.

3.2.9 Milled E-glass fibers mixed with Paragraph 3.2.13 epoxy resin system. Fiber ratio = 0.50 by weight.

3.2.10 Syntactic Foam - Emerson and Cumings FT-102 glass micro-balloons mixed with Paragraph 3.2.12 epoxy resin system. Mixing ratio 20 percent by weight (20 parts microballoons, 80 parts resin).

3.2.11 Syntactic Foam - Emerson and Cumings FT-102 glass micro-balloons mixed with Paragraph 3.2.13 epoxy resin system. Mixing ratio 20 percent by weight (20 parts microballoons, 80 parts resin).

3.2.12 APCO 2434/2347 epoxy resin system, 7.5 \pm 0.5 parts per hundred resin by weight (phr).

3.2.13 APCO 2434/2340 epoxy resin system, 27 \pm 1.0 phr.

3.2.14 Honeycomb core, HRH-10/OX-3/16-3.0 (3/8-inch thick).

3.2.15 Hardman "Extra Fast Setting Epoxy" adhesive.

3.2.16 Mold release: "Part-All #10," Rexco.

3.2.17 Mold wax: "Mirror Glaze" or equivalent.

- 3.2.18 Mold release: "Plastilease 334," Ram Chemical Co.
- 3.2.19 Mold release: "Ram 225," Ram Chemical Co.
- 3.2.20 Polyvinyl alcohol (PVA) emulsion or equivalent.
- 3.2.21 Film adhesive FR-7035 (nylon matte carrier) 0.03 lb per sq ft, Fiber Resin Corporation.
- 3.2.22 Skin surface material, 1 mil thick bondable both sides Tedlar film. 100 BM (PVF).
- 3.2.23 5056 aluminum screen, 120 mesh 4-mil wire diameter.
- 3.2.24 Polyurethane foam, density = 3 lb/ft³.
- 3.2.25 Peel ply nylon cloth, Miltex 3921 or equivalent (shop aid).
- 3.2.26 SP110 cleaner, J.S. Switzer Associates.
- 3.2.27 Tedlar film, bondable both sides 4 mil, Type 400 BG20. Dupont.
- 3.2.28 Polyurethane 0.025 inch thick, 5.25 inches wide, Dunlop Ltd.
- 3.2.29 Polyurethane adhesive, Furane 5747 A&B, or equivalent.
- 3.2.30 Eccosorb space cloth, Emerson and Cuming, Inc., see Volume III.
- 3.2.31 Release film.
- 3.2.32 Syntactic foam - Kurea A-200 carbon microballoon mixed with APCO 2434/2347 resin. Mixing ratio 20 percent by weight (20 parts microballoons and 80 parts resin).
- 3.2.33 10C-2 filler, Advanced Coatings and Chemical Co.
- 3.2.34 28W-1 surfacer, Advanced Coatings and Chemical Co.
- 3.2.35 HMS 15-1100, Type 1, primer.
- 3.2.36 Eccocoat CC-2, silver paint, Emerson and Cuming, Inc.
- 3.2.37 37038 black polyurethane paint, FED-STD-595.
- 3.2.38 34087 olive drab polyurethane paint, FED-STD-595.
- 3.2.39 Zinc chromate primer (TT-P-1757).
- 3.2.40 Polysulfide sealant.
- 3.2.41 Capon 80, vacuum bag material.

3.3	<u>Required Procedures and Operations</u>	<u>Inspection</u>
3.3.1	<u>Main Mold Preparation (surface and flanges of mold)</u>	
3.3.1.1	Apply layers of 2-inch-wide masking tape on both mold surfaces at blade tip to provide 1-inch-wide x 0.030-inch recess for tip cap.	O*
3.3.1.2	Apply Paragraph 3.2.17 mold wax and buff.	
3.3.1.3	Apply Paragraph 3.2.19 mold release very lightly (blend equal parts by weight).	
3.3.1.4	Spray mold with Paragraph 3.2.20 emulsion and cure at room temperature until tack free.	
3.3.1.5	Apply 230 gm of Paragraph 3.2.12 resin on each mold surface to prevent slipping of peel ply on skin.	O
3.3.1.6	Lay one disc of Paragraph 3.2.25 peel ply in each flange recess in the mold.	O
3.3.2	<u>Honeycomb Core Preparation (two required)</u>	
3.3.2.1	Bevel both long edges.	
3.3.2.2	Trim fore and aft edges.	
3.3.2.3	Attach pieces of honeycomb core to both mold surfaces with double-sticky masking tape on 10-inch centers, spanwise. Orient the ribbon direction perpendicular to the length. Bond joints 100 percent with Paragraph 3.2.15 adhesive. Orient all splice joints at $90^{\circ} \pm 10^{\circ}$ to the length.	
3.3.2.4	Apply core splice (one ply of Paragraph 3.2.5 glass fabric and Paragraph 3.2.13 resin).	

*O in "Inspection" column indicates points that must be signed off by quality control inspector.

- 3.3.2.5 Enclose in vacuum bag and cure at 130° F for 2 to 3 hours, or at room temperature overnight.
- 3.3.2.6 Trim core splice with flange extending 1/4 inch aft of trailing edge of honeycomb (see Figure 6).

O

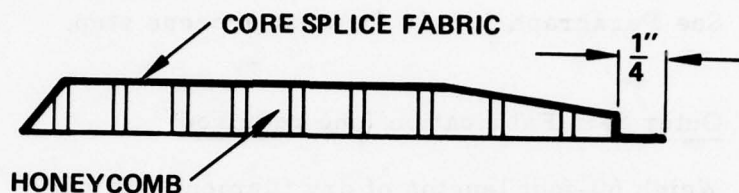


Figure 6. Honeycomb, core splice, and flange.

- 3.3.2.7 Fill aft two or three cells of honeycomb with urethane foam. Sand smooth. CAUTION: Do not bend honeycomb panel, to avoid delamination.
- 3.3.2.8 Inspect dimensions and for bond.
- 3.3.2.9 Cut off honeycomb core chordwise at BS 85.
- 3.3.2.10 Clean with air hose and store under dust cover until needed.
- 3.3.2.11 See Paragraph 3.3.16 for next process step.

O

3.3.3 Tray Fabrication (10 trays required)

- 3.3.3.1 Laminate one ply of Paragraph 3.2.5 glass fabric on patterns with Paragraph 3.2.13 resin system.
- 3.3.3.2 Apply Paragraph 3.2.25 peel ply - then enclose in vacuum bag and rub out.
- 3.3.3.3 Cure 8 to 10 hours at room temperature.

O

		<u>Inspection</u>
3.3.3.4	Trim to size.	
3.3.3.5	Inspect dimensionally.	O
3.3.3.6	Store in a plastic bag until needed.	
3.3.3.7	See Paragraph 3.3.16 for next process step.	
3.3.4	<u>Outer Skin Fabrication (one required)</u>	
3.3.4.1	Weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry-to wet-filament weight ratio should be 0.56 \pm 0.03.	
3.3.4.2	Set up the outer skin winding mandrel in the winding machine. Tape on two 1/4-inch-thick x 1-inch-wide wooden strips side by side at the trim line at both the top and the bottom of mandrel. Wrap the mandrel with Paragraph 3.2.31 nylon film. Measure the mandrel tare weight before winding.	O
3.3.4.3	Wind according to Table 6 with Paragraph 3.2.1 Kevlar-49 and Paragraph 3.2.12 resin.	O

TABLE 6. SKIN WINDING PROGRAM

No. Rovings	Winding Angle*	No. Circuits per pattern	No. Circuits per layer	Bandwidth** (inches)	No. Layers	No. Plies
15	90°	-	315***	0.90	-	1
15	$\pm 45^\circ$	5	49	0.90	1	-

* Tolerance = $\pm 5^\circ$

** Tolerance = ± 0.05 inch

*** For a length of 285 inches

		<u>Inspection</u>
3.3.4.4	The weight of the wound assembly must conform to the limits shown in weight record (Table 14).	O
3.3.4.5	Rub out surface with Teflon roller to flatten rovings and fill gaps.	
3.3.4.6	Wrap one layer of Paragraph 3.2.3 glass fabric to cover winding. Place splices along trim lines. Do not overlap. Smooth surface with paint roller. Apply 460 grams of Paragraph 3.2.12 resin on glass fabric for wetting peel ply (next process).	O
3.3.4.7	Wrap one layer of Paragraph 3.2.25 peel ply over Paragraph 3.2.3 glass fabric. Place splices along trim lines. Do not overlap. Smooth surface.	
3.3.4.8	This part may be stored up to 48 hours at room temperature.	
3.3.4.9	See Paragraph 3.3.16 for next process step.	
3.3.5	<u>Spar Longo Fabrication (two required)</u>	
3.3.5.1	Check to see that bushing fits mold.	
3.3.5.2	Surface treat and prime bushing surface per Paragraph 2.2.	
3.3.5.3	Measure hardback tare weight and mount hardback, tray, and bushing on longo winding fixture. Apply one piece of Paragraph 3.2.21 film adhesive between the flange of bushing and tray. Remove peel ply. Wet the upper and lower tray surfaces with Paragraph 3.2.12 resin. Tape down leading edge of tray.	O

		<u>Inspection</u>
3.3.5.4	Weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry- to wet-filament weight ratio must be 0.56 ± 0.03 .	
3.3.5.5	Wind the spar longo from Paragraph 3.2.1 Kevlar-49 and Paragraph 3.2.12 resin. Maximum winding tension is 4 to 6 pounds per band.	
3.3.5.6	Using 15 rovings per band, wind wraps as follows: <ol style="list-style-type: none"> Make seven wraps around end bushings. Add two pins at each end of hardback, starting at the center. Make seven wraps around end bushings, add four pins. Repeat steps b and c five times, for a total of seven circuits with seven wraps each. 	O
3.3.5.7	The weight of the wound assembly must conform to the limits shown in the weight record (Table 14).	O
3.3.5.8	If the wet winding is not to be used within 24 hours after winding, seal in plastic bag and store at temperature of $+40^{\circ}\text{F}$ maximum for up to 72 hours. After 72 hours this winding must be used immediately!	O
3.3.5.9	See Paragraph 3.3.16 for next process step.	
3.3.6	<u>Spar Broom Fabrication (two required -- wind both at same time)</u>	
3.3.6.1	Mount hardback and tray with peel ply removed on broom winding fixture. Coat the upper and lower surface of the tray with Paragraph 3.2.12 resin.	

		<u>Inspection</u>
3.3.6.2	Measure hardback tare weight and weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry- to wet-filament weight ratio must be 0.56 ± 0.03 .	O
3.3.6.3	Wind the broom from Paragraph 3.2.1 Kevlar-49 and Paragraph 3.2.12 resin. Maximum winding tension is 4 to 6 pounds per band.	
3.3.6.4	Using 15 rovings per band, wind 16 wraps around each pin on fixture (total of 13 pins).	O
3.3.6.5	The weight of the wound assembly must conform to the limits shown in the weight record (Table 14).	O
3.3.6.6	Store in cold box per Paragraph 3.3.5.8.	O
3.3.6.7	See Paragraph 3.3.16 for next process step.	
3.3.7	<u>Root End Reinforcement Laminate (two required)</u>	
3.3.7.1	Weigh 60-foot lengths of dry filament and wet filament. Dry- to wet-filament weight ratio should be 0.69 ± 0.03 .	
3.3.7.2	Wrap skin mandrel with release film (Paragraph 3.2.31).	
3.3.7.3	Wind using Paragraph 3.2.6 rovings and Paragraph 3.2.12 resin according to Table 7.	

TABLE 7. REINFORCEMENT WINDING PROGRAM

No. of Rovings	Winding Angle*	No. Circuits per Pattern	No. Circuits per Layer	Bandwidth** (inches)	No. Layers
12	$\pm 45^\circ$	5	50 ± 1	0.90	3

*Tolerance = $\pm 5^\circ$

**Tolerance = ± 0.05 inch

		<u>Inspection</u>
3.3.7.4	Use grooved Teflon roller to smooth the windings.	
3.3.7.5	Cut winding longitudinally and lay out flat on work table.	
3.3.7.6	Trim according to template and stack layers according to patterns. Remove release film for each layer. Cut holes for bushings.	O
3.3.7.7	Store in cold box per Paragraph 3.3.5.8.	O
3.3.7.8	See Paragraph 3.3.16 for next process step.	
3.3.8	<u>Trailing Edge Longo Fabrication (two required)</u>	
3.3.8.1	Check to see that bushing fits mold.	
3.3.8.2	Surface treat and prime bushing per Paragraph 2.2.	
3.3.8.3	Install aluminum screen (Paragraph 3.2.23) for upper trailing edge longo only, as follows: <ul style="list-style-type: none"> a. Clean and prime per Paragraph 2.3. b. Trim to planform of trailing edge longo template. c. Cut hole for bushing. d. Fit screen over bushing with straight edge of screen to the left of the bushing, looking down. e. Fit tray over screen. f. Brush with Paragraph 3.2.12 resin between all mating surfaces: bushing/tray/screen. 	O
3.3.8.4	Mount hardback, tray, aluminum screen, and bushing on longo winding fixture. Apply one piece of Paragraph 3.2.21 film adhesive between the flange of bushing and tray. Wet the upper and lower surfaces of the tray (after removing peel ply) and screen surfaces with Paragraph 3.2.12 resin.	

- 3.3.8.5 Measure hardback tare weight and weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry- to wet-filament weight ratio must be 0.607 ± 0.03 .
- 3.3.8.6 Wind trailing edge longos from Paragraph 3.2.2 graphite filaments and Paragraph 3.2.12 resin. Maximum winding tension is 4 to 6 pounds per band.
- 3.3.8.7 Wind per Table 8 using 10 rovings per band.

Inspection

O

TABLE 8. TRAILING EDGE LONGO WINDING PROGRAM

Blade Station	No. of Bands	Remarks
39.0 to 264.0	30	After 11 bands, insert Style 104 E-glass cloth between every two bands until 19 bands have been wound, Figure 7.

O

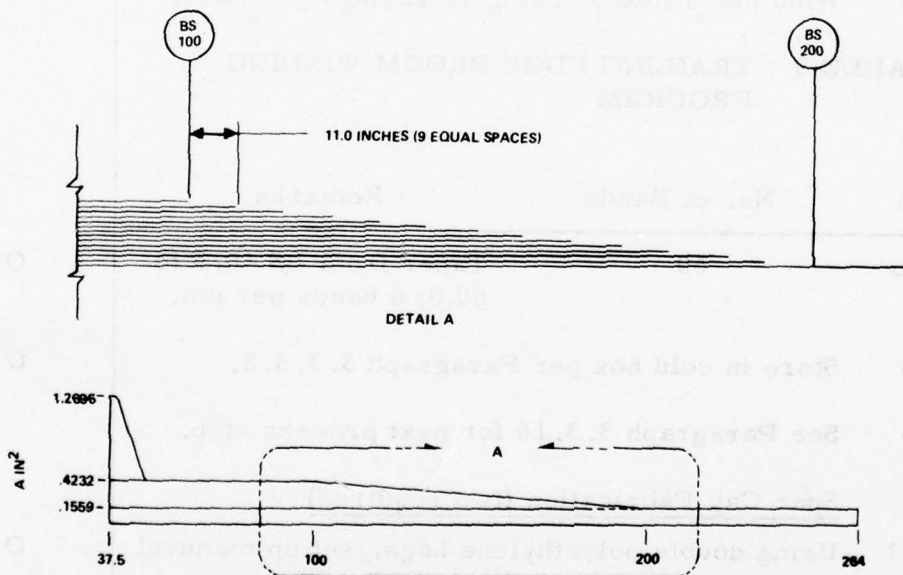


Figure 7. Trailing edge longo distribution chart.

		<u>Inspection</u>
3.3.8.8	The weight of the wound assembly must conform to the limits shown in the weight record (Table 14).	O
3.3.8.9	Store in cold box per Paragraph 3.3.5.8.	O
3.3.8.10	See Paragraph 3.3.16 for next process step.	
3.3.9	<u>Trailing Edge Broom Fabrication (two required)</u>	
3.3.9.1	Mount hardback and tray with peel ply removed on broom longo winding fixture. Coat the upper and lower surface of the tray with Paragraph 3.2.12 resin.	
3.3.9.2	Dry- to wet-filament weight ratio must be 0.607 ± 0.03 .	
3.3.9.3	Wind trailing edge longos from Paragraph 3.2.2 graphite filaments and Paragraph 3.2.12 resin. Maximum winding tension is 4 to 6 pounds.	
3.3.9.4	Wind per Table 9, using 10 rovings per band.	

TABLE 9. TRAILING EDGE BROOM WINDING PROGRAM

Blade Station	No. of Bands	Remarks	
39.0 to 50.0	60	Taper from BS 40.5 to 50.0; 6 bands per pin.	O
3.3.9.5	Store in cold box per Paragraph 3.3.5.8.		O
3.3.9.6	See Paragraph 3.3.16 for next process step.		
3.3.10	<u>Spar Cap Fabrication (two required)</u>		
3.3.10.1	Using double polyethylene bags, set up mandrel in winding machine. Apply initial pressure of 1 psi and verify that diameter is 8.60 ± 0.10 inches. Wrap Paragraph 3.2.21 film adhesive with film carrier.		O

		Inspection
3.3.10.2	Install 1-inch wide strip of Paragraph 3.2.30 space cloth on top of film adhesive on a straight line -- identify location on end of mandrel. (DO NOT USE TAPE FOR IDENTIFICATION.)	O
3.3.10.3	Measure mandrel tare weight and weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry- to wet-filament weight ratio must be 0.56 ± 0.03 .	O
3.3.10.4	Wind with Paragraph 3.2.1 Kevlar-49 and Paragraph 3.2.12 resin. Maximum winding tension is 4 to 6 pounds per band.	
3.3.10.5	Wind per Table 10. Verify that tube diameter is 8.90 ± 0.10 inches.	O

TABLE 10. SPAR CAP WINDING PROGRAM

Sequence No.	No. Rovings	Winding Angle*	No. Circuits per Pattern	No. Circuits per Layer	Bandwidth (in.)**	No. Layers	No. Plies	Mandrel Pressure# (psi)
1	16	$\pm 45^\circ$	4	19	1.00	1	-	4
2	16	$\pm 45^\circ$	1	47	1.00	1	-	8
3	16	$\pm 45^\circ$	1	47	1.00	1	-	12
4	16	90°	-	6 Hoop Plies at each end Dome				

Applicable for 6-pound winding tension - adjust if necessary for other tensions.

* Tolerance $\pm 5^\circ$.

** Tolerance ± 0.05 inch.

3.3.10.6	The weight of the wound assembly must conform to the limits shown in the weight record (Table 14).	O
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		<u>Inspection</u>
3.3.10.7	Cut away mandrel ends. Slowly and carefully remove metal mandrel, <u>inside polyethylene bag</u> , and adhesive film carrier. <u>NOTE:</u> Before removing ends, orient the space cloth location and identify this edge as forward edge. <u>CAUTION:</u> Do <u>NOT</u> stretch winding. This may decrease the width of spar cap.	O
3.3.10.8	Check that flattened width of spar cap = 13.90 \pm 0.25 inches.	O
3.3.10.9	Remove end tooling and fold the winding flat along one edge of space cloth and identify edge.	
3.3.10.10	Apply vacuum bag over flattened spar and hardback. Maintain vacuum in bag until ready to install spar cap in mold.	
3.3.10.11	Store in cold box per Paragraph 3.3.5.8.	
3.3.10.12	See Paragraph 3.3.16 for next process step.	
3.3.11	<u>Leading Edge Longo Fabrication (one required, lower half)</u>	
3.3.11.1	Mount hardback and tray with peel ply removed on longo winding fixture. Coat the upper and lower surfaces of the tray with Paragraph 3.2.12 resin.	
3.3.11.2	Measure hardback tare weight and weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry- to wet-filament weight ratio must be 0.728 \pm 0.03.	O
3.3.11.3	Wind leading edge longos from Paragraph 3.2.6 roving and Paragraph 3.2.12 resin. Maximum winding tension is 4 to 6 pounds per band.	

		<u>Inspection</u>
3.3.11.4	Using 15 rovings per band, wind 120 wraps around simulated forward bushing and inboard tip pin. Wind 58 wraps around simulated forward bushing and outboard tip pin.	O
3.3.11.5	The weight of the wound assembly must conform to the limits shown in the weight record (Table 14).	O
3.3.11.6	Store in cold box per Paragraph 3.3.5.8.	O
3.3.11.7	See Paragraph 3.3.16 for next process step.	
3.3.12	<u>Leading Edge Longo Fabrication (one required, upper half)</u>	
3.3.12.1	Mount hardback and tray on longo winding fixture. Coat the upper and lower surfaces of the tray with Paragraph 3.2.12 resin. Measure hardback tare weight.	O
3.3.12.2	Using 15 rovings per band, wind 178 wraps around the simulated forward bushing and the midtip pin. Use Paragraph 3.3.11.2 dry- to wet-fiber weight ratio and Paragraph 3.3.11.3 filament tension.	O
3.3.12.3	The weight of the wound assembly must conform to the limits shown in the weight record (Table 14).	O
3.3.12.4	Store in cold box per Paragraph 3.3.5.8.	O
3.3.12.5	See Paragraph 3.3.16 for the next process step.	
3.3.13	<u>Main Spar Tube Fabrication (four required)</u>	
3.3.12.1	Surface treat and prime surface of tip weight for No. 1 spar tube per Paragraph 2.4.	O
3.3.13.2	Surface treat and prime surface of tip weight for No. 2 spar tube per Paragraph 2.3.	O

		<u>Inspection</u>
3.3.13.3	Install tip weight on winding shaft for spar tubes No. 1 and 2. Wrap tip weight with Paragraph 3.2.21 film adhesive. Punch holes in film adhesive to allow free air passage through 1/8-inch-diameter hole. Identify the spar tube number on each winding shaft.	O
3.3.13.4	Install styrofoam spacers on winding shaft. <u>CAUTION:</u> Do <u>NOT</u> reinforce styrofoam with Paragraph 3.2.15 adhesive.	
3.3.13.5	Install inner polyethylene bag and Paragraph 3.2.27 bladder on mandrel.	
3.3.13.6	Install keys to index the tip weight with respect to the index shaft collar. Identify orientation of each tip weight on winding shaft.	O
3.3.13.7	Install mandrel in winding machine.	
3.3.13.8	Check bladder for leak under initial winding pressure and seal leaks if any.	O
3.3.13.9	Measure mandrel tare weight and weigh 60-foot lengths of dry filament and wet filament before beginning to wind part. Dry- to wet-filament weight ratio must be 0.56 ± 0.03 .	O
3.3.13.10	Set up mandrel in winding machine and apply sufficient tension on winding shaft to control droop at midspan.	
3.3.13.11	Apply initial internal bladder pressure of 2 psi and verify that bladder diameter is 2.52 to 2.58 inches for tubes No. 1, 2, 3, and 4.	O
3.3.13.12	Weigh 2 ± 1 gm per inch of mandrel length of Paragraph 3.2.12 resin system and apply the whole amount uniformly over the entire surface of the bladder. Wind sequence No. 1 of Table 11 with dry roving.	

TABLE 11. MAIN SPAR TUBE WINDING PROGRAM

Sequence No.	No. Rovings	Winding Angle*	No. Circuits per Pattern	No. Circuits per Layer	Bandwidth (in.)**	No. Layers	No. Plies	Mandrel Pressure (psi)***
1	16	90°	1	****	0.940	-	1	3
2	16	±45°	1	6	0.940	1	-	6
3	16	±45°	1	6	0.940	1	-	9
4*****	16	±45°	1	6	0.940	1	-	12
5	16	90°	1	****	0.940	-	1	15

* Tolerance = ±5°

** Tolerance = ±0.05 inch

*** Applicable for 6-pound winding tension - adjust if necessary for other tensions.

**** Tubes No. 1 and 2 - 265 circuits per layer for a length of 253 inches

Tubes No. 3 and 4 - 303 circuits per layer for a length of 282 inches

***** For Tube No. 4 only - Apply three layers of two-inch-wide reinforcing strips wound under Paragraph 3.3.7 (±45°) per sketch. Orient all glass tapes on straight line and identify azimuthal and longitudinal orientation on winding shaft prior to winding sequence No. 4.

DO NOT USE TAPE FOR MARKING.

BS 30 _____ BS 85

_____ BS 175

_____ BS 220

Inspection

3.3.13.13 Wrap six to eight hoops to pull the bladder into the tip weight neck for the No. 1 and No. 2 spar tubes. NOTE: Wrap one ply of Paragraph 3.2.5 glass fabric between tip weight neck and adjacent end dome, with minimum 2-inch overwrap. Wrap one uniform hoop over fabric. CAUTION: Tie Tedlar bag in neck down area with fabric to prevent roving cutting the Tedlar bag.

3.3.13.14 Wind all four tubes with Paragraph 3.2.1 Kevlar-49 and Paragraph 3.2.12 resin. Maximum winding tension shall be 4 to 6 pounds per band.

3.3.13.15 Wind tubes per winding program in Table 11.

O

		<u>Inspection</u>
3.3.13.16	Verify that tube diameter of tubes No. 1, 2, 3 and root end of No. 4 tube is 2.58 to 2.70 inches. Verify that tip-end diameter of No. 4 tube is 2.55 to 2.67 inches.	O
3.3.13.17	Check wound tubes for leaks at 35 psi. Make new tube if leak is found.	O
3.3.13.18	The weight of the wound assembly must conform to the limits specified in the weight record (Table 14). <u>NOTE</u> : Use plastic film-covered aluminum angle to support the wet-wound tubes while handling.	O
3.3.13.19	Store in cold box per Paragraph 3.3.5.8 with sufficient pressure to hold winding pattern (1 to 3 psi). <u>CAUTION</u> : Support on plastic film-covered aluminum angle.	O
3.3.12.20	See Paragraph 3.3.16 for next process step.	
3.3.14	<u>Aft Tube Fabrication (one required)</u>	
3.3.14.1	Install mandrel with polyethylene bag inside Tedlar bladder in winding machine. <u>CAUTION</u> : Do not use any Paragraph 3.2.15 adhesive.	
3.3.14.2	Check bladder for leaks under initial winding pressure and seal leaks if any.	O
3.3.14.3	Laminate one ply of Paragraph 3.2.5 glass fabric 18 to 24 inches long at each end of the mandrel with 6 inches minimum overlap. Use Paragraph 3.2.12 resin while the mandrel is inflated 0.5 to 1 psig. Loosely wrap with Kevlar roving to tie it in place.	
3.3.14.4	Weigh 60-foot lengths of dry filament and wet filament before beginning to wind tube. Dry-to wet-filament weight ratio must be 0.686 ± 0.03 .	
3.3.14.5	Apply 0.5 to 1 psig internal bladder pressure and verify that the bladder diameter is 4.84 to 4.99 inches.	O

		<u>Inspection</u>
3.3.14.6	Wind with Paragraph 3.2.6 glass rovings and Paragraph 3.2.12 resin. Maximum winding tension is 4 to 6 pounds per band. Wind $\pm 55^\circ$ helical layers ($\pm 5^\circ$ tolerance) using 11 rovings with 10 circuits per layer. Bandwidth is 0.87 ± 0.05 inch. Wind one layer only using a minimum mandrel pressure of 1.5 psig.	O
3.3.14.7	Verify that tube diameter is 4.88 to 5.00 inches. <u>NOTE:</u> Absolute maximum is 5.00 inches!	O
3.3.14.8	Install band clamp on each dome to prevent winding from sliding. Use glass fabric and rubber strip to protect winding from damage by band clamp.	O
3.3.14.9	Store in cold box per Paragraph 3.3.5.8 with sufficient pressure to hold winding pattern.	O
3.3.14.10	See Paragraph 3.3.16 for next process step.	
3.3.15	<u>Doily Fabrication (two required)</u>	
3.3.15.1	Wind doily from Paragraph 3.2.6 glass roving and Paragraph 3.2.12 resin. Fiber ratio by weight must be 0.686 ± 0.03 . Maximum winding tension is 4 to 6 pounds per band.	
3.3.15.2	Using 15 rovings per band, wind 14 wraps.	O
3.3.15.3	Store in cold box per Paragraph 3.3.5.8.	O
3.3.15.4	See Paragraph 3.3.16 for next process step.	
3.3.16	<u>Assembly Sequence (applies to both the upper and lower half molds unless otherwise specified)</u>	
3.3.16.1	Use nails on 4- to 6-inch centers, fasten 1-inch-thick by 1-inch-wide wooden strips over longitudinal trim lines on top and bottom of skin mandrel. Apply 2-inch-wide masking tape centered over circumferential trim line, 264 inches apart, at both ends of skin mandrel.	

Inspection

- 3.3.16.2 Cut the outer skin winding at trim lines. Temporarily hold two cut halves on winding mandrel by stapling two adjacent wooden strips together at approximately 12-inch intervals. Mark center line on both halves of winding at each end.
- 3.3.16.3 Align centerline of half-winding to the center of mold surface and place skin on mold (nylon peel ply against mold surface).
- 3.3.16.4 Trim skin back to the mold depression and discard excess material. NOTE: Edge of trim line must be inboard of step.
- 3.3.16.5 Cut holes in the skin over the flange recesses to match diameter of forward and aft bushing flanges.
- 3.3.16.6 Rub out with paint roller. CAUTION: Roll in chordwise direction -- do not disturb winding pattern. NOTE: Use paint roller to remove air bubbles -- use grooved Teflon roller to remove wrinkles.
- 3.3.16.7 Remove plastic film. CAUTION: Do not disturb winding pattern.
- 3.3.16.8 Install trailing edge locator and trailing edge longo template.
- 3.3.16.9 Install a strip of Paragraph 3.2.21 film adhesive on the skin from a point 6 inches forward of the blade trailing edge to the aft edge of the honeycomb panel -- from BS 85 to tip. Coat open-cell side of honeycomb with Paragraph 3.2.12 resin using steel roller. Install honeycomb core against trailing edge longo template using weight to hold it in position.

O

O

- | | Inspection |
|--|------------|
| 3.3.16.10 While on hardback, rub out spar longo first with slotted Teflon roller, then finish with Teflon paddle to attain uniform pattern. Longo width outboard of BS 85 is 11.75 inches. | O |
| 3.3.16.11 Remove spar longo (Paragraph 3.3.5) from hardback using carrying strips and install with flange bushing in mold recess and longo tray fitted to mold. Line up trailing edge of longo with edge of honeycomb core. Line up forward edge of longo 11.75 inches forward of forward edge of honeycomb. Fill tray cavity with Paragraph 3.2.8 milled fiber. CAUTION: Do not allow milled fiber to lift tray. NOTE: Install clamp fixture to hold down bushings. | O |
| 3.3.16.12 Rub out spar broom per Paragraph 3.3.16.10 while cutting the layers to a taper per Figure 8. Remove separation strips. | O |

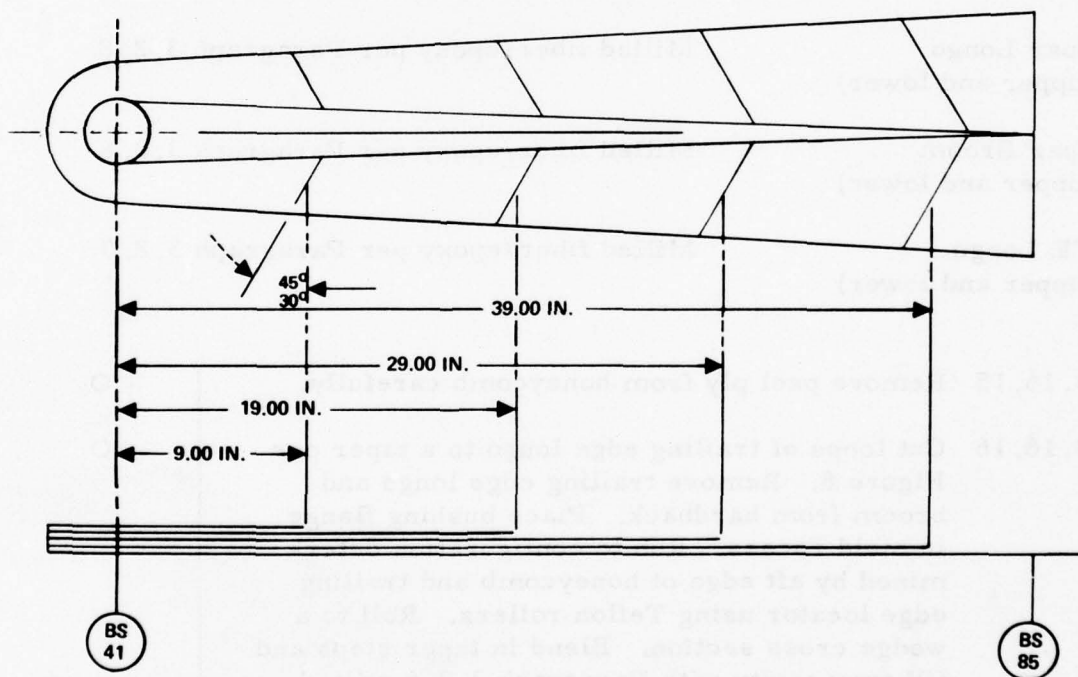


Figure 8. Spar broom trim pattern.

		<u>Inspection</u>
3.3.16.13	Remove spar broom (Paragraph 3.3.6) from hardback, brush bushing surface with Paragraph 3.2.12 resin and install over spar longo on flanged bushing. Fair step-tapered ends of broom longos with milled fiber. <u>CAUTION:</u> Do not allow milled fiber to lift tray. Use flange bushing holding tool to compress fiber.	
3.3.16.14	Fill cavity in tray per Table 12. Fair in space between spar longo and leading edge corner with milled fiber per Paragraph 3.2.8.	O

TABLE 12. TRAY CAVITY FILLER

Component	Filler	
LE Longo (upper and lower)	Syntactic foam per Paragraph 3.2.10 except first 3 inches at outboard tip of wedge where Paragraph 3.2.8 milled fiber must be used	
Spar Longo (upper and lower)	Milled fiber/epoxy per Paragraph 3.2.8	
Spar Broom (upper and lower)	Milled fiber/epoxy per Paragraph 3.2.8	
TE Longo (upper and lower)	Milled fiber/epoxy per Paragraph 3.2.8	
3.3.16.15	Remove peel ply from honeycomb carefully.	O
3.3.16.16	Cut loops of trailing edge longo to a taper per Figure 8. Remove trailing edge longo and broom from hardback. Place bushing flange in mold recess. Rub to configuration determined by aft edge of honeycomb and trailing edge locator using Teflon rollers. Roll to a wedge cross section. Blend in taper steps and fill tray cavity with Paragraph 3.2.8 milled fibers.	O

		<u>Inspection</u>
3.3.16.17	Cut the loops of the trailing edge longo broom. Brush bushing surfaces with Paragraph 3.2.12 resin. Install broom over trailing edge longo in mold.	O
3.3.16.18	Fill cavity in tray per Table 12. <u>CAUTION:</u> Do not allow milled fiber to lift tray.	O
3.3.16.19	Blend in taper steps using Paragraph 3.2.8 milled fiber.	
3.3.16.20	Coat syntactic foam filler block with Paragraph 3.2.12 resin and install to the aft edge of the spar longo and in the aft mold recess area just forward of the trailing edge longo. <u>NOTE:</u> Fill corner cavities at end of part of blade root end with syntactic foam per Paragraph 3.2.10 as required.	O
3.3.16.21	Install root-end reinforcement laminate (Paragraph 3.3.7) with the big side down, taper steps facing up. <u>NOTE:</u> Fill cavity around bushing with Paragraph 3.2.8 milled fiber.	
3.3.16.22	Rub out root-end reinforcement laminate with paint roller.	
3.3.16.23	Install inboard honeycomb panel with a strip of Paragraph 3.2.21 film adhesive on open-cell side of honeycomb directly under the beveled surface. Splice two honeycomb panels together with syntactic foam. <u>NOTE:</u> Trim edge of 1/4-inch glass cloth overlap at root end as required.	
3.3.16.24	Recheck honeycomb location. At BS 37.5, leading edge step must be 12.87 inches from trailing edge. Coat the cloth-covered side of honeycomb core with Paragraph 3.2.12 resin in a uniform coverage using paint roller.	O

Inspection

- 3.3.16.25 Install doily (Paragraph 3.3.15) over aft bushing. Apply Paragraph 3.2.10 syntactic foam to area aft of doily to blend edges.
- 3.3.16.26 Install thermocouples per Figure 9.
- 3.3.16.27 Punch hole for root-end bushing in spar cap (Paragraph 3.3.10) 4.5 inches from leading edge. CAUTION: Make sure space cloth is at forward edge of spar cap. Install spar cap with 0.1 to 0.2 inch above forward edge of the mold (Figure 10). Fill gaps around hole with milled fiber, Paragraph 3.2.8.
- 3.3.16.28 Rub out spar cap with paint roller. CAUTION: Roll in chordwise direction -- do not disturb winding pattern.
- 3.3.16.29 Apply clamp ring to compress spar cap, root-end reinforcement laminate, spar broom, spar longo, and skin to dimension that allows leading edge longo and tray to fit over forward bushing.
- 3.3.16.30 Fill holes in all-metal bushing with PVC foam (shop aid).

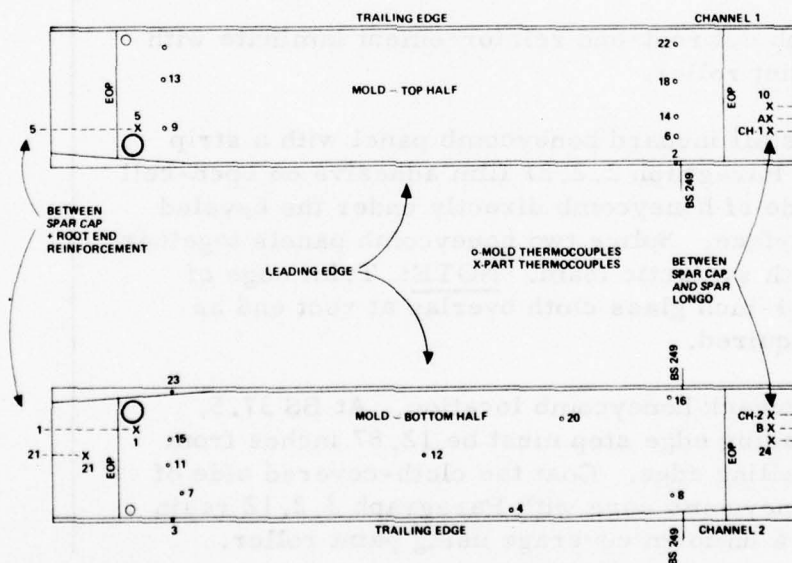


Figure 9. Thermocouple location.

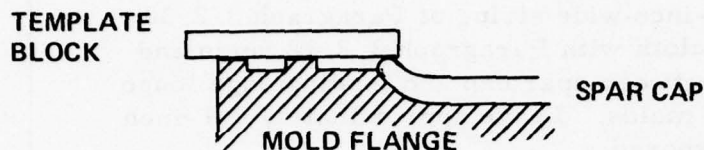


Figure 10. Spar cap alignment.

- 3.3.16.31 Fill trailing edge longo voids as required with Paragraph 3.2.32 syntactic foam to assure interference fit in pinch areas.
- 3.3.16.32 Install leading edge root-end fillets coated with Paragraph 3.2.12 resin.
- 3.3.16.33 Install film adhesive vacuum diaphragm (Paragraph 3.2.21). CAUTION: Add a plastic film to protect film adhesive from being damaged by locators (next process steps). Reinstall trailing edge longo locator over the diaphragm. Cover both ends of honeycomb (beyond end of part) with rubber strip to protect vacuum bag.
- 3.3.16.34 Install leading edge longo locator.
- 3.3.16.35 Pull back the vacuum diaphragm over the leading edge longo locator (Paragraph 3.3.16.33). CAUTION: Cover exposed film adhesive with plastic film to prevent leading edge longo and fillet from sticking to film adhesive. Remove leading edge longos (Paragraph 3.3.11) from hardback.
- 3.3.16.36 Install leading edge longos in mold with tray placed over forward bushing and fitted to mold. Trim tray to conform with longo path at root-end transition.

O

		Inspection
3.3.16.37	Coat 1-inch-wide strips of Paragraph 3.2.30 space cloth with Paragraph 3.2.12 resin and place between spar cap and leading edge longo in both molds. Leave approximately 0.1-inch edge exposed.	O
3.3.16.38	Surface treat and prime the leading edge tip weight per Paragraph 2.4.	O
3.3.16.39	Coat the leading edge tip weight with Paragraph 3.2.12 resin and install in the loop formed in the tip end of the lower mold leading edge longo. Pin the nose tip weight to mold. NOTE: Fill cavities with Paragraph 3.2.10 syntactic foam as required. Fit urethane foam fillet (shop aid) at outboard end of tip weight to protect vacuum diaphragm. NOTE: On upper mold add syntactic foam filler to outboard end of leading edge longo to match slope of nose tip weight. Fill cavities with syntactic foam as required.	O
3.3.16.40	Remove the plastic film cover installed in Paragraph 3.3.16.35.	
3.3.16.41	Unfurl the vacuum diaphragm and smooth over the leading edge longo. Use shop aid materials to protect sharp corners and edges beyond end of part. Seal diaphragm to mold with zinc chromate around the edge of the mold. Install vacuum line at each end of mold. <u>CAUTION:</u> Avoid pinch-off of vacuum line by any blade components, particularly the movable mold.	O
3.3.16.42	Draw vacuum (26 inches Hg) and check for leaks and material movement. Remove leading edge and trailing edge locators.	
3.3.16.43	Check that beveled surface of honeycomb has 0.010-inch interference with respect to chord plane. Build up with Paragraph 3.2.21 film adhesive as required.	O

Inspection

- 3.3.16.44 Remove protective backing material from film adhesive on stationary mold.
- 3.3.16.45 Rig guide brackets for No. 4 and 5 spar tubes.
- 3.3.16.46 Release pressure on spar tubes No. 1 and 2 and aft tube. Crush foam spacers in spar tubes No. 1 and 2 and in aft tube using a flat board. Restore pressure in tubes to 1 to 3 psi.
- 3.3.16.47 Install four spar tubes and aft tube in lower mold per following sequence with internal pressure released. NOTE: Place rubber protective strips at the edge of mold ends.
- 3.3.16.48 Install tensioning collar on tubes No. 3, 4, and 5. CAUTION: Check for clearance between the mold and the collar. Tension and pressurize tubes in the following sequence:
- No. 4 tube - Place in mold with reinforced side toward trailing edge - tension and pressurize to 15 to 20 psig - use spar tube guide bracket to locate aft side and root end.
 - No. 3 tube - Tension and pressurize to 15 to 20 psig.
 - No. 1 tube } - Zero pressure - carefully shape
No. 2 tube } - into position.
 - No. 5 tube - Tension and pressurize to 2 to 3 psig - use spar tube guide bracket to locate aft side. CAUTION: Do not bend aft tube winding shaft excessively.
- 3.3.16.49 Release pressure in aft tube.
- 3.3.16.50 Remove all guide brackets on stationary mold.

O

O

		<u>Inspection</u>
3.3.16.51	Remove the protective backing material from the film adhesive vacuum diaphragm on movable mold. Maintain vacuum. NOTE: Tape rubber protective strips at edge of mold ends.	
3.3.16.52	Release all pressure in the five spar tubes. CAUTION: Disconnect ALL pressure lines from manifold and open valves.	O
3.3.16.53	Use six threaded rods (one at each corner and midspan of mold) as guides. Lower upper mold slowly to allow air in the tubes to escape and maintain level closing without rocking. Close the mold, tightening tie bolts at the trailing edge first; then the leading edge. Tightening sequence begins from middle of the mold, then proceeds outboard at the same time.	O
3.3.16.54	Verify full contact of the mold flanges.	
3.3.16.55	Pressurize mold tubes to 15 to 20 psig.	O
3.3.16.56	Pressurize the spar tubes to 5 to 10 psig in the following sequence: No. 4 tube (shut off pressure line to tube before proceeding to next tubes). No. 3 and 5 tubes simultaneously (shut off pressure line to tubes before proceeding to next tubes). No. 1 and 2 tubes simultaneously.	O
3.3.16.57	Cure the blade according to the following schedule and record temperature, pressure, and time through cure cycle.	O
3.3.16.58	Pressurize internal tubes to 35 psig - two cycles over a 10-minute period. Reduce pressure to 15 to 20 psig. NOTE: Measure pressure at dead end of mandrels. Pressure readings should be same within gage tolerance.	O

		<u>Inspection</u>
3.3.16.59	Hold 15 to 20 psig pressure in the five spar tubes <u>and</u> in the mold tubes until mold temperature reaches 130° to 150° F. Use separate air sources to pressurize the blade and mold tubes. CAUTION: Mold tube pressure must never exceed the blade tube pressure.	O
3.3.16.60	Use infrared lamps at both ends of the mold to heat the exposed ends of the spar tubes to a maximum of 130° F as measured on the tubes.	O
3.3.16.61	When the mold temperature reaches 130° to 150°F, increase the pressure in the spar tubes to 33 to 37 psig.	O
3.3.16.62	Hold the 130° to 150°F temperature for 4 to 6 hours.	O
3.3.16.63	Increase the heating power to the mold and, when the mold temperature passes through 200° F, release vacuum and lower the blade tube pressure to 15 to 20 psig. CAUTION: Mold tube pressure must never exceed the blade tube pressure. Move infrared lamps closer to obtain at least 200° F at the exposed ends.	O
3.3.16.64	When the mold temperature reaches 230° to 250°F, hold mold temperature and hold the blade and mold tube pressure at 15 to 20 psig for 4 to 6 hours.	O
3.3.16.65	Hold the spar tube pressure constant and cool mold to 90° to 100° F. Then release the pressure and open the mold.	
3.3.17	<u>Final Assembly</u>	
3.3.17.1	Check the Barcol hardness of blade surface at the root, tip, and midspan locations, top and bottom, over the spar cap area. Record these measurements in Table 14.	O

		<u>Inspection</u>
3.3.17.2	Fill No. 1 and 2 spar tube cavities 6-1/2 to 7 inches deep from the root end with milled fiber/epoxy (Paragraph 3.2.9). Fill No. 3, 4, and 5 tube cavities with syntactic foam (Paragraph 3.2.11) 1/4 ±1/16 inch deep from root end and 1/4 ±1/16 inch deep from tip end. Use end dams to trap fillers. Bond 1/8-inch-thick PVC foam filler to outboard ends of No. 1 and 2 spar tube tip weights.	O
3.3.17.3	Remove nylon peel ply from the skin only at the areas for bonding of leading edge cap, tip cap, root cap, and trim cap.	O
3.3.17.4	Apply 2.4-inch wide strip of Paragraph 3.2.30 space cloth over the leading edge. Centrally locate over split line. Laminate leading edge cap of four plies of Paragraph 3.2.5 glass fabric cut at a bias. Use Paragraph 3.2.13 resin.	O
3.3.17.5	Laminate a tip cap from three plies of Paragraph 3.2.5 glass fabric at tip and per Drawing 503-001. Use Paragraph 3.2.13 resin.	O
3.3.17.6	Trim blade and verify dimensions per Drawing 503-001. Remove polyethylene bags from all spar tubes.	O
3.3.17.7	Fill cavity between spar tubes and tip weights with Paragraph 3.2.10 syntactic foam for approximately 3 inches by drilling 1/8-inch hole in tip weight.	O
3.3.17.8	Laminate a root-end cap from six plies of Paragraph 3.2.5 glass fabric per Drawing 503-001. Use Paragraph 3.2.13 resin.	O
3.3.17.9	Vacuum bag leading edge cap and root cap with Paragraph 3.2.41 material at 26 inches Hg and rub out well. Tip cap uses contact layup only.	O

		<u>Inspection</u>
3.3.17.10	Bond on trim tab using Paragraph 3.2.13 resin. Verify location per Drawing 503-001.	O
3.3.17.11	Drill bleed holes through tip cap into <u>all</u> spar tubes. Cure blade at 180° to 200° F for 2 to 3 hours.	O
3.3.17.12	Remove excess flash on laminates and maintain drawing requirements. Chase all threads in tip weights.	O
3.3.17.13	Install tracking tab per Drawing 503-001.	O
3.3.18	<u>Final Machining</u>	
3.3.18.1	Machine the blade root bushings in general accordance with Drawing 503-001 Sheet 3. Additional specific details are described in the following paragraphs.	
3.3.18.2	All machining shall be done WITHOUT liquid cutting lubricants.	O
3.3.18.3	Face off the flange surfaces of the blade root bushings flat and parallel according to Figure 11.	O
3.3.18.4	Measure outside diameters of sleeves. Based on these diameters, selectively bore the blade root bushings according to the dimensions in Table 13.	O
3.3.18.5	Apply Paragraph 3.2.39 zinc chromate primer to all exposed surfaces of flanged root bushings.	O

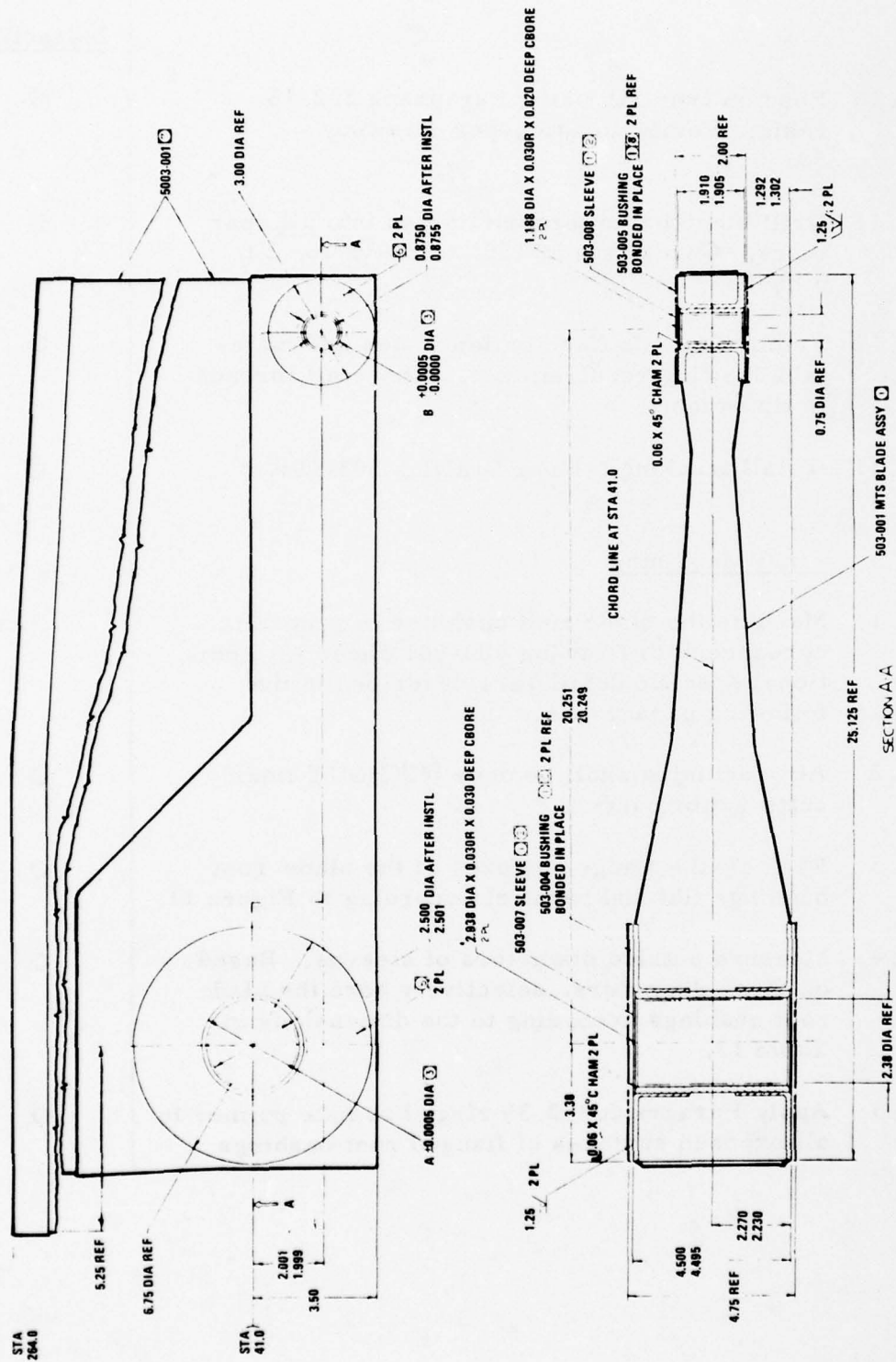


Figure 11. Blade root machining dimensions.

TABLE 13. SELECTIVE BORING DIMENSIONS

Calculations to determine selective-fit hole sizes (Ref Figure 11)

Material:

17 - 4 PH stainless steel

Coefficient of thermal expansion = 6×10^{-6} in./in./°F

Temperature reduction = +70° F to -320° F = -390° F

Diameter "A" = (Sleeve dia) - (Sleeve dia \times 390 \times 6×10^{-6}) + 0.0032

Diameter "B" = (Sleeve dia) = (Sleeve dia \times 390 \times 6×10^{-6}) + 0.0011

Sample Calculation (Typical)

Example with measured sleeve diameters of 2.875 and 1.125

Dia "A" = 2.875 - (2.875 \times 390 \times 6×10^{-6}) + 0.0032 = 2.8715

Dia "B" = 1.125 - (1.125 \times 390 \times 6×10^{-6}) + 0.0011 = 1.1235

Clearance Check:

Sleeve Diameter (inches)	Cold Sleeve Diameter (inches)	Hole Diameter (inches)	Cold Fit Clearance (inches)	Final Interference Fit (inches)
2.875	2.8683	2.8710	0.0027	0.0040
		2.8720	0.0037	0.0030
1.125	1.1224	1.1235	0.0011	0.0015
		1.1240	0.0016	0.0010

		<u>Inspection</u>
3.3.18.6	Install sleeves cold per Paragraph 2.5 specification with sleeve temperature not lower than -320° F. CAUTION: At this temperature the sleeves must be handled with care because they are easily fractured.	O
3.3.18.7	Bore, counterbore, and chamfer sleeves according to Figure 11.	O
3.3.19	<u>Painting</u>	
3.3.19.1	Remove peel ply from the top and bottom surfaces of the blade. Make sure surface is dry, clean and free of oil, grease, and wax.	O
3.3.19.2	Wipe Paragraph 3.2.33 pinhole filler onto the surface with clean rags, rubbing filler into voids with a circular motion. Allow to stand until the residue turns white and dry. Then wipe off excess material with a clean wiper cloth.	O
3.3.19.3	Spray 1-mil-thick Paragraph 3.2.34 sanding surfacer on the blade surfaces. Air dry for 1 hour at ambient conditions followed by 1 hour at 150° to 180°F.	O
3.3.19.4	Sand the surfaces lightly with No. 200- to 400-grit sandpaper per Paragraph 2.6 specification. CAUTION: Be careful not to abrade the Kevlar surfaces. Clean the sand surfaces with tack rags and then with aliphatic naphtha solvent.	O
3.3.19.5	Apply one coat, 0.8 to 1.2 mil thick, of Paragraph 3.2.35 primer. Air dry for 3 to 4 hours at ambient condition.	O

		<u>Inspection</u>
3.3.19.6	Mask the leading edge of the blade back to a line 4.0 inches aft of the leading edge. Mask the ends of the blade at the root and tip.	O
3.3.19.7	Spray one coat of Paragraph 3.2.26 silver paint, 1 mil thick in a continuous wet film. (Adjust to the proper consistency for spray application by adding butyl acetate solvent.)	O
3.3.19.8	Air dry for 2 hours at ambient temperature followed by 1 hour at 180° to 200° F. THEN REMOVE THE MASKING.	O
3.3.19.9	Repeat the Paragraph 3.3.19.5 process over the silver paint.	O
3.3.19.10	Spray the bottom surface of the blade with Paragraph 3.2.37 black paint and the top surface with Paragraph 3.2.38 olive drab paint.	O
3.3.19.11	Air dry for 6 to 8 hours at ambient conditions.	O
3.3.20	<u>Leading Edge Erosion Strip Application</u>	
3.3.20.1	Support the blade in the leading edge "up" position and wipe the leading edge of the blade with methylethylketone (MEK) to remove dirt and oil.	O
3.3.20.2	Cut strips of Paragraph 3.2.28 erosion material approximately 6 feet long.	
3.3.20.3	Remove protective backing strip and moisten the adhesive backing of the erosion strip with MEK.	
3.3.20.4	Beginning at the tip of the blade and working in-board, lay the erosion strip along the leading edge of the blade and work it chordwise with gloved hands to cover all the leading edge recess. Use a "rubber stitcher" to roll out all air bubbles.	O

		<u>Inspection</u>
3.3.20.5	Fair edges of erosion strip to blade with Paragraph 3.2.40 sealant.	O
3.3.20.6	Sand sealant smooth.	O
3.3.20.7	Wipe leading edge strip adjacent to butt joints with MEK.	O
3.3.20.8	Cover butt joints with 2-inch-wide strips of erosion material using Paragraph 3.3.20.4 method.	O
3.3.21	<u>Final Inspection</u>	
3.3.21.1	Inspect blade for completion per Drawing 503-001.	O
3.3.21.2	Weigh the blade and record its weight in Table 14.	O

TABLE 14. WEIGHT RECORD FOR BLADE S/N-006,
S/N-007 AND S/N-008

Item No.	Part Name	Tool Weight (tare)	Tool Weight (postwind)	Component Weight (as measured)	Weight (lb) Limits	Winding Length (in.)
1	Outer Skin	_____	_____	_____	16.25 - 17.25	286.0
2	Spar Longo No. 1	_____	_____	_____	7.00 - 7.50	286.5
3	Spar Longo No. 2	_____	_____	_____	7.00 - 7.50	286.5
4	Spar Broom Longo Pair	_____	_____	_____	5.15 - 5.50	
5	Root End Reinforcement No. 1	_____	_____	_____	8.89 - 9.45	
6	Root End Reinforcement	_____	_____	_____	8.89 - 9.45	
7	TE Longo No. 1	_____	_____	_____	2.85 - 3.05	264.0
8	TE Longo No. 2	_____	_____	_____	2.85 - 3.05	264.0
9	Spar Cap No. 1*	_____	_____	_____	25.1 - 26.7	285.0
10	Spar Cap No. 2*	_____	_____	_____	25.1 - 26.7	285.0
11	LE Longo (Lower Mold)	_____	_____	_____	25.15 - 26.75	222.25
12	LE Longo (Upper Mold)	_____	_____	_____	24.0 - 25.5	189.0
13	Spar Tube No. 1**	_____	_____	_____	5.14 - 5.46	284.0
14	Spar Tube No. 2	_____	_____	_____	5.14 - 5.46	282.0
15	Spar Tube No. 3	_____	_____	_____	5.33 - 5.01	282.0
16	Spar Tube No. 4***	_____	_____	_____	5.33 - 5.01	282.0

Finished Blade Weight _____ lb

Barcol Hardness, Spar Area

Top Surface

Bottom Surface

Root _____

Root _____

Midspan _____

Midspan _____

Tip _____

Tip _____

*With film adhesive

**With reinforcing strip

***With fabric and hoop winds at extension

4. QUALITY ASSURANCE PROVISIONS.

4.1 Responsibility for Inspection. The supplier of all basic materials used in the MTS blade shall be responsible for assuring their quality. The blade manufacturer shall be responsible for the quality of all processed components.

The blade manufacturer's inspectors shall be responsible for selecting rolls of dry filaments to achieve the dry weight control defined in the footnote to Table 5. They shall also be responsible for ascertaining the filament/resin weight ratio for each blade element, as well as the weight of each tubular or longo element fabricated by the WFW process and for maintaining the weight record (Table 14).

The blade manufacturer's inspectors shall be responsible for seeing that all elements of the blade are properly wound, assembled, and finished.

Paragraph 3.3 indicates inspection points that must be signed off.

CONCLUSIONS

The WFW, co-cure process uses raw materials at their lowest possible cost and assembles them largely by low-labor-intensive automated methods to produce a very low-cost blade. Based on conservative assumptions for translation into 1000-blade-per-year production, it is demonstrated that the MTS blade can be produced for the WFW, co-cure process for a cost less than that for equivalent blades made by the two most prominent alternate processes:

- a. Metal Technology -- because even though composite materials have higher intrinsic costs, the automation afforded by WFW minimizes labor.
- b. Prepreg Technology -- because the extra prepreg step more than doubles the already high composite material cost and overwhelms the labor savings that automated layup allows.

The manufacturing process is well developed; the MTS blade for the AH-1G or this type of blade for any other helicopter can be purchased originally at lower cost than any other equivalent blade. After tooling and learning costs are amortized, the production price is estimated to be \$5050 per blade in FY 1976 dollars. The MTS blade has at least a 3600-hour fatigue life, is rugged, has good ballistic tolerance, and is highly repairable -- features that contribute to a long service life. Because these blades cost less than the current production metal blades and can remain in service much longer, the Army could realize significant savings by equipping its AH-1G fleet with these new blades.

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APPENDIX A

MTS BLADE FABRICATION TOUCH-TIME RECORD

While fabricating the MTS blades, careful records were taken of the touch-time associated with each function. Table A-1 is a summary of all the work done to fabricate the S/N-008 blade as represented by the eight elements listed in Table 2. Table A-2 is a more detailed breakdown of the touch-time data. Table A-3 compares filament winding touch-times for S/N-001, -002, and -008 blades.

TABLE A-1. MTS BLADE MANUFACTURING PROCESS STEPS -
TOUCH-TIME SUMMARY DATA* - S/N-008

Process Step	Item	Touch-Time (man-minutes)	
1	Mold and Tooling Preparation		
	a. Mandrels and Bags	1080	
	b. Longo Fixture Setup	720	
	c. Mold Surface Preparation	480	
	d. End Dams	480	
	e. Mount Mandrels	520	
	f. Mount Hardbacks	320	
			3600
2	Parts Prefabrication		
	a. Trays	1200	
	b. Honeycomb	1440	
	c. Root-End Reinforcement Doubler	600	
	d. Root-End Filler Blocks	960	
	e. Acid Etch Metal Parts	240	
			4440
3	Winding		
	a. Tubular Elements	1620	
	b. Longo Element	1080	
			2700

TABLE A-1 — Continued

Process Step	Item	Touch-Time (man-minutes)	
4	Assembly and Cure		
	a. Assembly	3360	
	b. Mold Closing	360	
	c. Curing	720	
	d. Mold Opening	240	4680
5	Trim and Finish		
	a. Trim and Finish	2640	
	b. Paint	480	
			3120
6	Leading Edge Erosion Strip		
	a. Bond in Place	240	
			240
7	Final Machining		
	a. Machine Root-End Bushings	720	
			720
8	Balancing		
	a. Balance Against Mating Blade	480	
			480
	TOTAL	19,980	
		(333 man-hours)	

*See Table A-2 for details

TABLE A-2. DETAILED BREAKDOWN OF MTS BLADE
TOUCH-TIME EXPERIENCE

Process Step	Item	Man-Minutes
1	Mold and Tooling Preparation	
	1a. <u>Mandrels and Bags</u>	Bladder Fabrication (man-minutes)
	Two spar caps	480
	Four spar tubes	480
	One aft tube	120
	One skin	-
	Total	1080
	1b. <u>Longo Fixture Setup</u>	Hardback Preparation
	Two spar longo	180
	Two broom longo (one hardback)	60
	Two TE longo	180
	Two TE broom (one hardback)	120
	Two LE longo	180
	Total	720
	1c. <u>Mold Surface Preparation</u>	
	Clean, apply mold release and polish, apply wax and polish, apply zinc chromate seals - two men for 4 hours	480
	1d. <u>End Dams</u>	
	Filler blocks, spar tube protectors, vacuum lines - two men for 4 hours	480

TABLE A-2 - Continued

Process Step	Item	Man-Minutes	
1 (cont)	1e. <u>Mount Mandrel</u>		
	<u>Element</u>	<u>Men</u>	<u>Minutes</u>
	No. 1 spar tube	2	25
	No. 2 spar tube	2	20
	No. 3 spar tube	2	15
	No. 4 spar tube	2	20
	No. 5 spar tube	2	15
	Upper spar cap	2	25
	Lower spar cap	2	20
	Skin	2	70
	Broadgoods for doubbers	2	50
			100
			520
	1f. <u>Mount Hardback</u>		
	Upper spar longo	2	20
	Lower spar longo	2	20
	Broom longos	2	15
	Upper LE longo	2	25
	Lower LE longo	2	20
	Upper TE longo	2	20
	Lower TE longo	2	20
	Upper TE broom	2	15
	Lower TE broom	2	5
			10
			320
2	Parts Prefabrication		
	2a. <u>Trays</u> (layup and trim)		
	Two spar longo		240
	Two broom longo		240
	Two LE longo		240
	Two TE longo		240
	Two TE broom		240
	(20 man-hours)		1200

TABLE A-2 — Continued

Process Step	Item	Man-Minutes	
2 (cont)	2b. <u>Honeycomb Preparation</u>		
	Set milling machine	240	
	Milling	600	
	Install foam at edge of panel	120	
	Bond on glass cloth	360	
	Finish	120	
	(24 man-hours)		1440
	2c. <u>Root-End Reinforcement Doublers</u>		
	Mandrel preparation	120	
	Winding	180	
	Trim to pattern	300	
	(10 man-hours)		600
3	2d. <u>Filler Blocks</u> (6 pieces)		
	Two men for 7.5 hours (16 man-hours)		960
	2e. <u>Acid Etch Metal Components</u>		
	One man for 4 hours (4 man-hours)		240
	Wet Filament Winding		
	3a. <u>Tubular Elements</u>	<u>Men</u>	<u>Minutes</u>
	No. 1 spar tube	2	60
	No. 2 spar tube	2	60
	No. 3 spar tube	2	65
	No. 4 spar tube	2	195*
	No. 5 spar tube	2	30
	Upper spar cap	2	110
	Lower spar cap	2	110
	Skin	2	90
	Broadgoods for doublers	2	90
	Total		1620

*Includes incorporating diagonally wound S-glass reinforcing

TABLE A-2 - Continued

Process Step	Item		Man-Minutes	
3 (cont)	3b. <u>Longo Elements</u>	<u>Men</u>	<u>Minutes</u>	
	Upper spar longo	3	30	90
	Lower spar longo	3	30	90
	Broom longos*	2	60	120
	Upper LE longo	3	90	270
	Lower LE longo	3	90	270
	Upper TE longo	3	30	90
	Lower TE longo	3	30	90
	Upper TE broom	2	15	30
	Lower TE broom	2	15	30
	Total			1080
4	Assembly and Cure			
	a. Assembly - seven men for 8 hours			3360
	b. Mold closing - six men for 1 hour			360
	c. Curing - one man for 12 hours			720
	d. Mold opening - four men for 1 hour			240
				4680
5	Trim, Finish and Cleanup			
	a. Trim and finish - two men for 22 hours			2640
	b. Paint - two men for 4 hours			480
				3120
6	Leading Edge Erosion Strip			
	a. Four men for 1 hour			240
				240
7	Final Machining			
	a. One man for 12 hours			720
				720
8	Balancing			
	a. Two men for 4 hours			480
				480

*Wound two at a time

TABLE A-3. FILAMENT WINDING - MTS BLADES

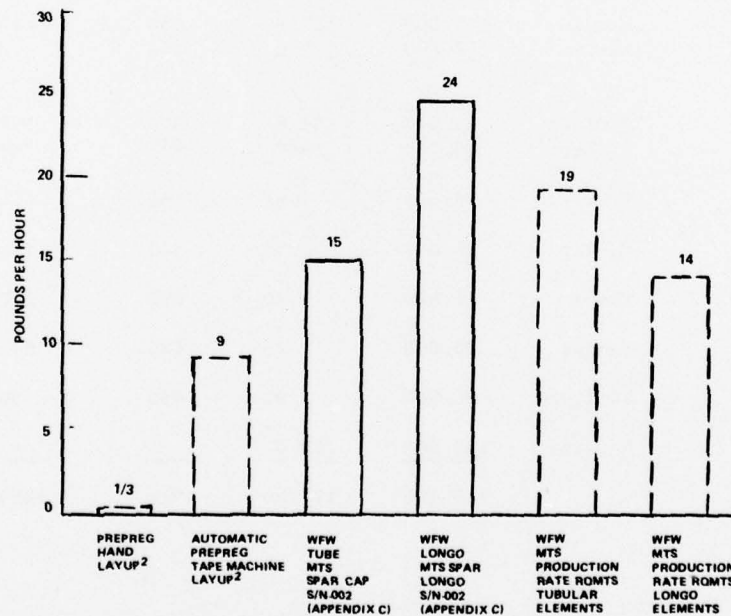
Component	Material	Roving Length (feet)	Wet Weight (lb)	Measured Touch-Times (man-minutes)		
				S/N-001	S/N-002	S/N-008
Outer Skin - Winding	Kevlar	75,000	16.75	675	180	180
Spar Longo - Winding						
Upper	Kevlar	38,000	7.3	105	135	90
Lower	Kevlar	38,000	7.3	90	54	90
Spar Broom - Winding						
Upper and Lower	Kevlar	30,000	5.3	180	125	120
TE Longo						
Upper	Thornel	15,000	2.95	450	105	90
Lower	Thornel	15,000	3.25	36	75	90
TE Longo Broom						
Upper	Thornel	1,200	0.25	90	30	30
Lower	Thornel	1,200	0.25	45	30	30
Spar Cap						
Upper	Kevlar	147,000	27.8	450	280	220
Lower	Kevlar	147,000	27.8	450	220	220
LE Longo						
Upper	S-Glass	82,000	24.8	300	170	270
Lower	S-Glass	86,000	25.9	345	325	270
Spar Tube No. 1	Kevlar	25,000	4.85	180	160	120
Spar Tube No. 2	Kevlar	25,000	4.85	300	100	120
Spar Tube No. 3	Kevlar	25,000	5.20	195	270	130
Spar Tube No. 4	Kevlar	25,000	7.25	585	510	390
Spar Tube No. 5	S-Glass	10,000	3.00	450	90	60
Broadgoods	S-Glass	<u>150,000</u>	<u>23.0</u>	-	-	<u>180</u>
TOTALS		935,400	197.80	4926	2859	2700

APPENDIX B

WET COMPOSITE MATERIAL LAYUP RATES

An important aspect of the WFW process, when considering high production rates, is the number of pounds of impregnated filaments that can be deposited each hour in a configuration that can be used directly in the final assembly. Figure B-1 compares these rates for different composite material fabrication processes. This chart shows that while fabricating the MTS blade, WFW tubular elements were wound at a rate of 15 pounds per hour, and WFW longo elements were laid down at a rate of 24 pounds per hour.

To produce MTS blades at a rate of 1000 blades per year, it would be necessary to wind tubular elements at 19 pounds per hour, and longos at 14 pounds per hour. HH/FSI have already demonstrated longo winding rates 50 percent in excess of this requirement, and tubular winding rates equal to 100 percent of that required. FSI can now demonstrate the ability to surpass this rate on a dual spindle tube winding machine that winds two tubular elements simultaneously. Hence, the WFW filament delivery technology meets current requirements.



² Douglas, L.K., and Stratton, W.K., COMPOSITE STRUCTURES - TECHNICAL BREAKTHROUGH FOR HELICOPTER ROTOR BLADES, Boeing Vertol Company, SAE Paper 751108, Society of Automotive Engineers, Warrendale, Pennsylvania, November 1975.

Figure B-1. Wet composite material layup rates.

APPENDIX C

COMPOSITE MATERIAL PROCESSING COST COMPARISON

The WFW process uses the filament and resin materials in their lowest cost form -- dry filaments and bulk resin. To get them into a usable form, they are combined and wound into a tubular or longo configuration, in one operation. Figures C-1 and C-2 show typical costs for WFW material. Figure C-1 represents the fabrication of a tubular element: the MTS blade spar cap. Figure C-2 is for the fabrication of a unidirectional filament component: the MTS blade spar longo. Both are made from Kevlar-49.

The cost of fabrication by the WFW process and by using Kevlar-49 prepreg tape or broadgoods is developed in Table C-1 and shown in Figures C-1 and C-2. It is seen that the WFW process allows the basic materials to be combined and wound into usable components for approximately 50 percent of the cost at which the prepreg material can be purchased. After acquisition the prepreg material must still be formed, at additional cost, into the final configuration in which it will be used, either by hand layup or by automated layup.

TABLE C-1. UNIT COST CALCULATIONS

1. MTS SPAR CAP COST (Figure C-1)			
Labor	Touch-Time* (man-hours)	Cost Rate** (dollars/hr)	Manufacturing Cost (dollars)
Prepare Bag and Film Adhesive	2	1.39×15	41.80
Mandrel Set-up	1	1.39×15	20.90
Winding	4	1.39×15	83.60
Labor Total			146.30
Materials	Unit Cost		Manufacturing Cost (dollars)
Capron-80 Film	$\$2.45/\text{lb} \times 2.26 \text{ lb}$		5.54
FR-7035 Film Adhesive	$\$0.50/\text{ft}^2 \times 53.6 \text{ ft}^2$		26.80
Kevlar Fiber	$\$8.50/\text{lb} \times 1/2 \times 27.8 \text{ lb}$		118.15
APCO Resin	$\$1.87/\text{lb} \times 1/2 \times 27.8 \text{ lb}$		25.93
Material Total			176.42
+ 10% Scrap			17.64
			194.06
Labor and Material Total			\$340.36
Finished Weight			27.8 lb
Cost Per Pound			\$ 12.24
2. MTS SPAR LONGO COST (Figure C-2)			
Labor	Touch-Time (man-hours)	Cost Rate, (dollars/hr)	Manufacturing Cost (dollars)
Hardback Preparation and Mounting	2	1.39×15	41.80
Winding	1.5	1.39×15	31.35
Labor Total			73.15
Materials	Unit Cost		Manufacturing Cost (dollars)
Kevlar Fiber	$\$8.50/\text{lb} \times 1/2 \times 7.3 \text{ lb}$		31.03
APCO Resin	$\$1.87/\text{lb} \times 1/2 \times 7.3 \text{ lb}$		6.83
Material Total			37.86
+ 10% Scrap			3.79
			41.65
Labor and Material Total			114.80
Finished Weight			7.3 lb
Cost Per Pound			\$ 15.77
*See Table A-2 of Appendix A			
**Assumes 1.39 support factor and \$15 hour burdened labor rate.			

TABLE C-1 - Continued

3. PREPREG TAPE SPAR CAP COST ESTIMATE (Figure C-1)			
<u>Labor</u>			
Auto-tape layup ³	$\frac{2 \text{ man-hours}}{9 \text{ lbs}} \times \frac{27.8 \text{ lb}}{1 \text{ spar}}$	$\times 1.39 \times \$15/\text{man-hour}$	\$129.11
<u>Materials</u>			
Kevlar Uni-tape Prepreg	$\$25/\text{lb} \times (27.8 + 2.78)$		\$764.50
Total			\$893.61
Finished Weight			27.8 lb
Cost Per Pound			\$ 32.14
<hr/>			
<u>Labor</u>			
Hand Layup ⁴	$\frac{1 \text{ man-hour}}{0.33 \text{ lb}} \times \frac{27.8 \text{ lb}}{1 \text{ spar}}$	$\times 1.39 \times \$15/\text{man-hour}$	\$1760.57
<u>Materials</u>			
Kevlar Uni-tape Prepreg ⁴	$\$25/\text{lb} \times (27.8 + 2.78)$		\$ 764.50
Total			\$2525.07
Finished Weight			27.8 lb
Total Cost Per Pound			\$ 90.82
<hr/>			
4. PREPREG TAPE SPAR LONGO COST ESTIMATE (Figure C-2)			
<u>Labor</u>			
Auto-tape layup ³	$\frac{2 \text{ man-hours}}{9 \text{ lb}} \times \frac{7.3 \text{ lb}}{1 \text{ spar}}$	$\times 1.39 \times \$15/\text{man-hour}$	\$ 33.90
<u>Materials</u>			
Kevlar Uni-tape Prepreg ⁴	$\$25/\text{lb} \times (7.3 + 0.73 \text{ lb})$		\$200.75
Total			\$234.65
Finished Weight			7.3 lb
Cost Per Pound			\$ 32.14
<hr/>			
<u>Labor</u>			
Hand Layup ³	$\frac{1 \text{ man-hour}}{0.33 \text{ lb}} \times \frac{7.3 \text{ lb}}{1 \text{ spar}}$	$\times 1.39 \times \$15/\text{man-hour}$	\$462.31
<u>Materials</u>			
Kevlar Uni-tape Prepreg ⁴	$\$25/\text{lb} \times (7.3 + 0.73 \text{ lb})$		\$200.75
Total			\$663.06
Finished Weight			7.3 lb
Cost Per Pound			\$ 90.82

³ Scarpati, T.S., Feenan, R.J., and Stratton, W.K., THE RESULTS OF FABRICATION AND TESTING OF THE PROTOTYPE COMPOSITE ROTOR BLADES FOR HLH AND UTTAS, Boeing Vertol Company, AIAA Paper No. 75-1010, American Institute of Aeronautics and Astronautics, New York, August 1975.

⁴ Adams, K.M., and Luchs, J.J., STUDY TO INVESTIGATE DESIGN, FABRICATION AND TEST OF LOW COST CONCEPTS FOR LARGE HYBRID COMPOSITE HELICOPTER FUSELAGE, PHASE I, Sikorsky Aircraft Division, United Technologies Corp.; NASA CR-132731, Langley Directorate, U.S. Army Air Mobility Research and Development Laboratory, Hampton, Virginia, June 1975.

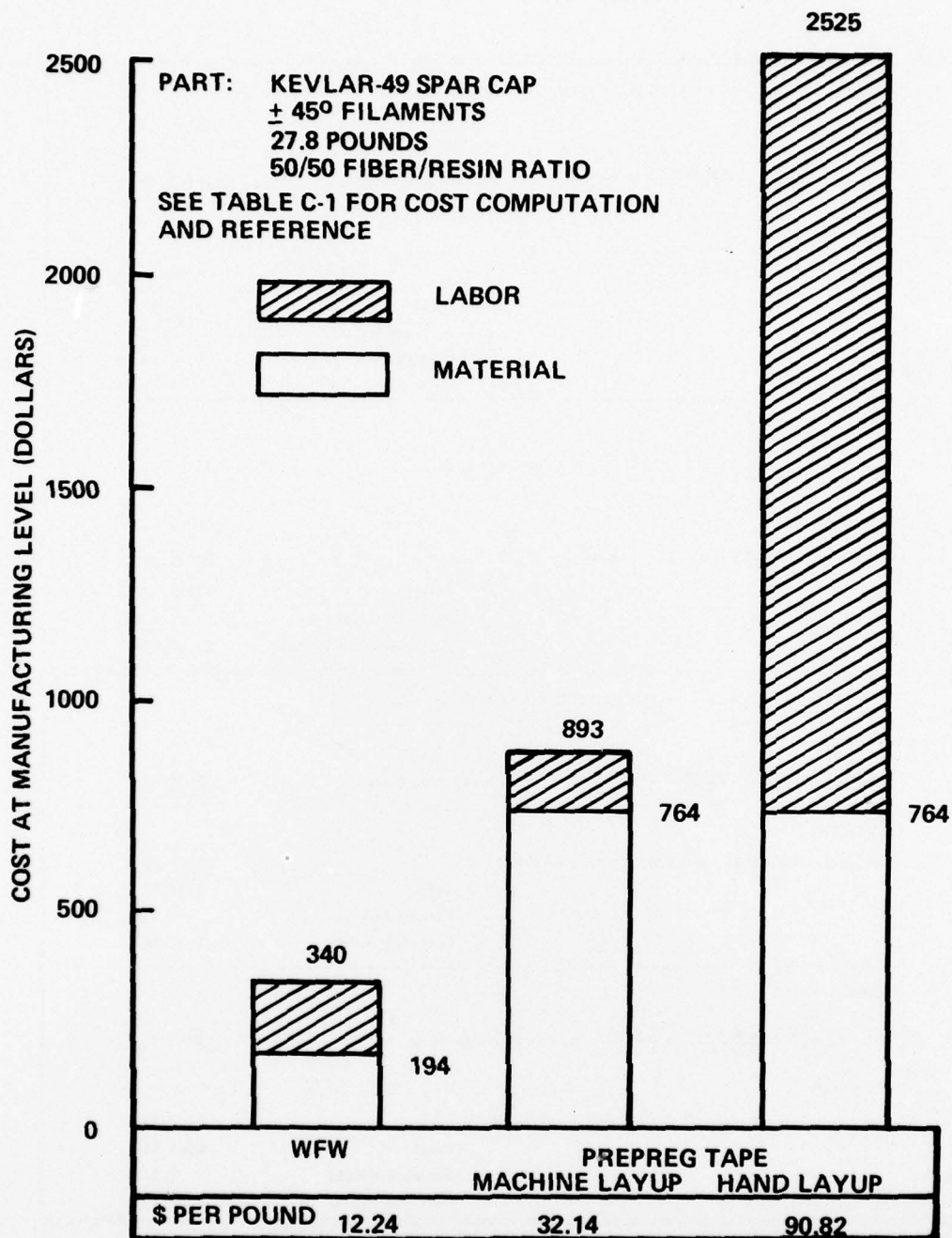


Figure C-1. Cost comparison, tubular element wet-filament winding versus prepreg tape.

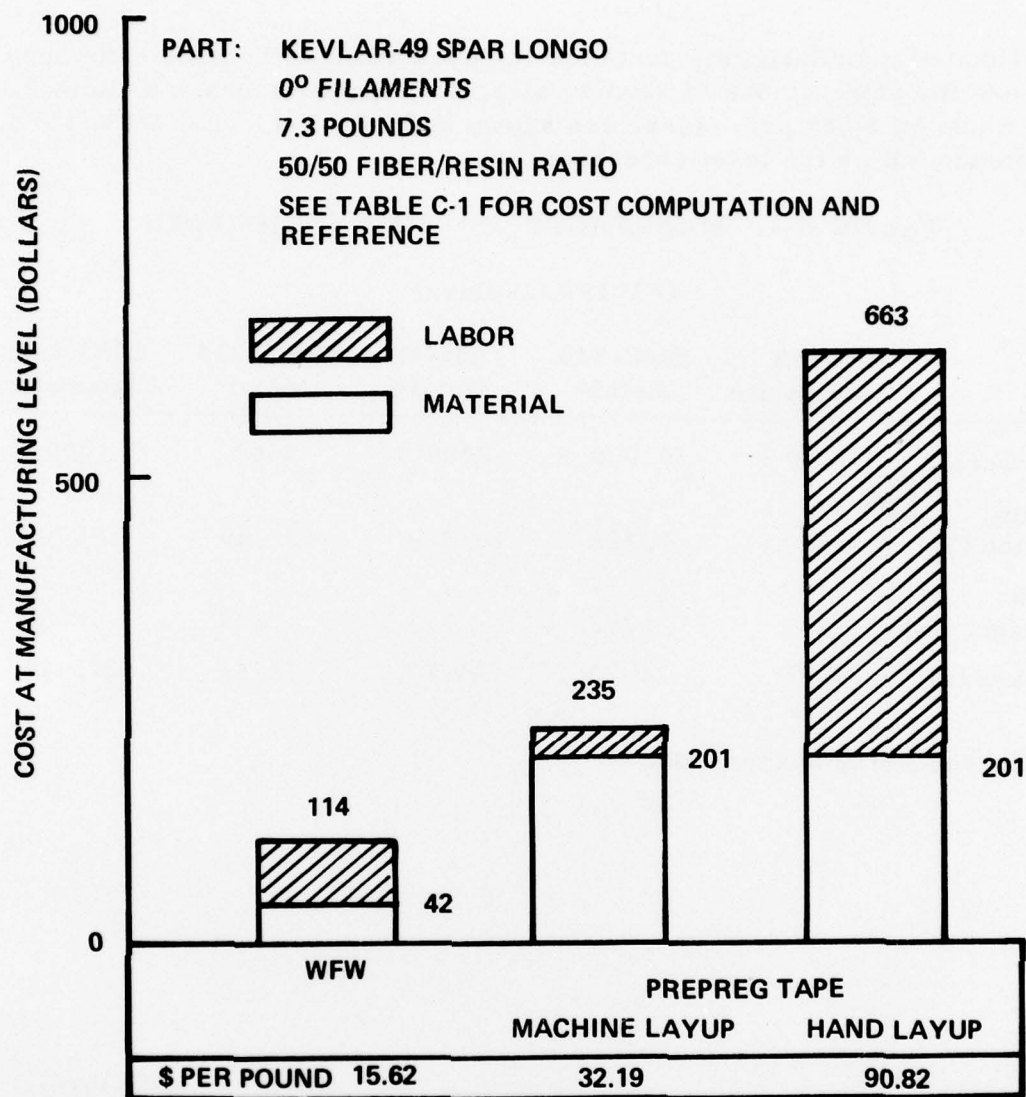


Figure C-2. Cost comparison, longo element -- wet filament winding versus prepreg tape.

APPENDIX D

BLADE MANUFACTURING METHOD COST COMPARISON

The estimated manufacturing costs for the production MTS blade compared with those for other blades of similar size, both metal blades and composite blades made by other processes, are shown in Table D-1. The WFW MTS blade stands out as the least expensive.

TABLE D-1. MANUFACTURING COST COMPARISON

(FY 1976 Dollars)

	MTS Composite	BHC-540 Metal*	CH-47 Metal*	BHC-214 Metal ⁵	BHC-214 Composite ⁵
Unit Serial	2000 +	10,000 +	2000 +	1000	1000
Selling Price (\$)	5050	7,722	10,959	12,940	11,970
Blade Weight (lb)	232	232	315	400	400
Dollars/lb	21.76	24.20	34.79	32.35	29.91

*Estimated Army Spares Cost

⁵ Anderson, R. G., and Covington, C. E., COMPOSITE MAIN ROTOR BLADE FOR THE 214 HELICOPTER, Bell Helicopter Textron, AHS Preprint No. 1051, American Helicopter Society, Washington, D. C., May 1976.

APPENDIX E
TOOLS AND FIXTURES

<u>Photograph</u>	<u>Equipment</u>
E-1	Winding mandrel, outer skin
E-2	Winding mandrel, spar tube
E-3	Winding fixture, longo
E-4	Longo hardbacks
E-5	Bonding fixture, bladder
E-6	Blade mold
E-7	Impregnator, resin
E-8	Locating gage, spar tube

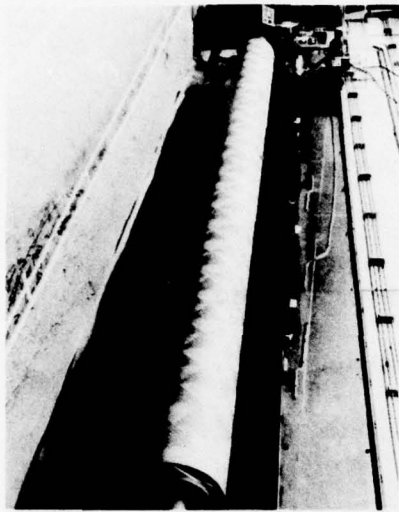


Figure E-1. Winding mandrel, outer skin.

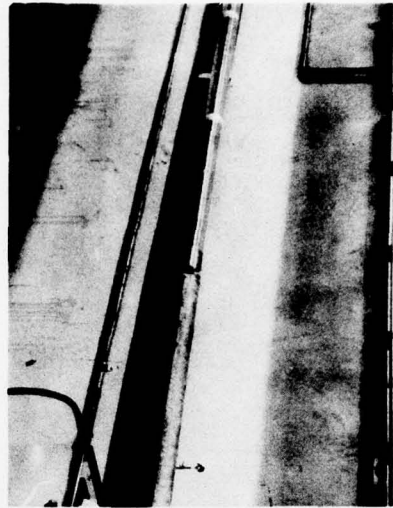


Figure E-2. Winding mandrel, spar tube.

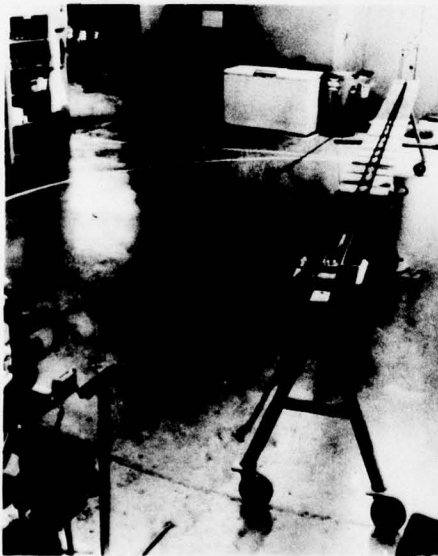


Figure E-3. Winding fixture, longo.

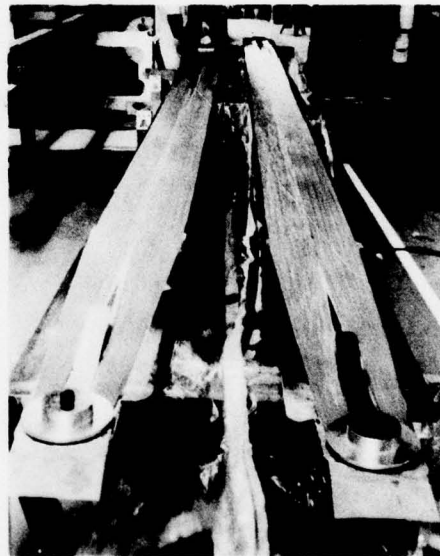


Figure E-4. Longo hardbacks.



Figure E-5. Bonding fixture, bladder.

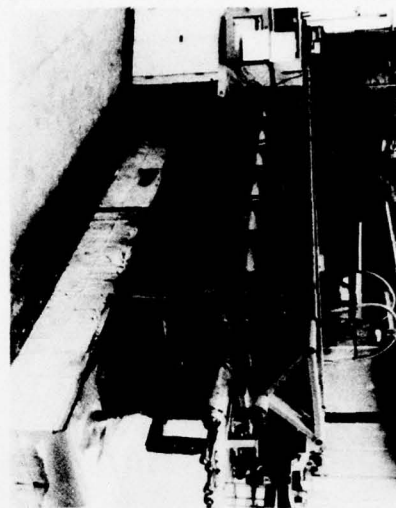
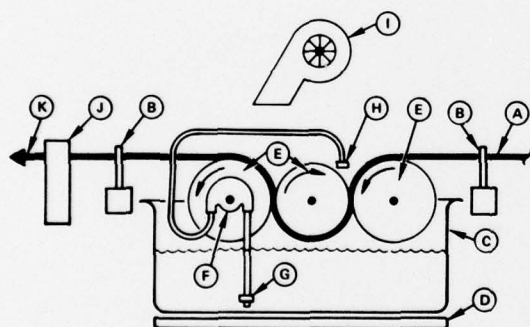


Figure E-6. Blade mold.



- A. DRY ROVING BAND FROM SPOOLS OF FILAMENTS
- B. COMB TO ALIGN FILAMENTS
- C. RESIN RESERVOIR
- D. RESERVOIR HEATER
- E. IMPREGNATION ROLLER (3)
- F. SYSTOLIC PUMP
- G. PUMP INLET WITH METERING ORIFICE
- H. RESIN DISPENSING OUTLET
- I. HOT AIR BLOWER
- J. WINDING EYE TO ALIGN FILAMENTS
- K. WET FILAMENT BAND TO WINDING MACHINE (4 TO 6 POUNDS TENSION)

Figure E-7. Impregnator, resin.

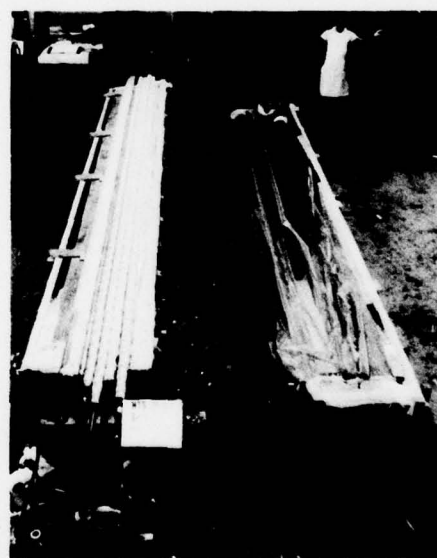


Figure E-8. Locating gage, spar tube.